Robot assisted aortic surgery

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ROBOT ASSISTED AORTIC SURGERY

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ROBOT ASSISTED AORTIC SURGERY

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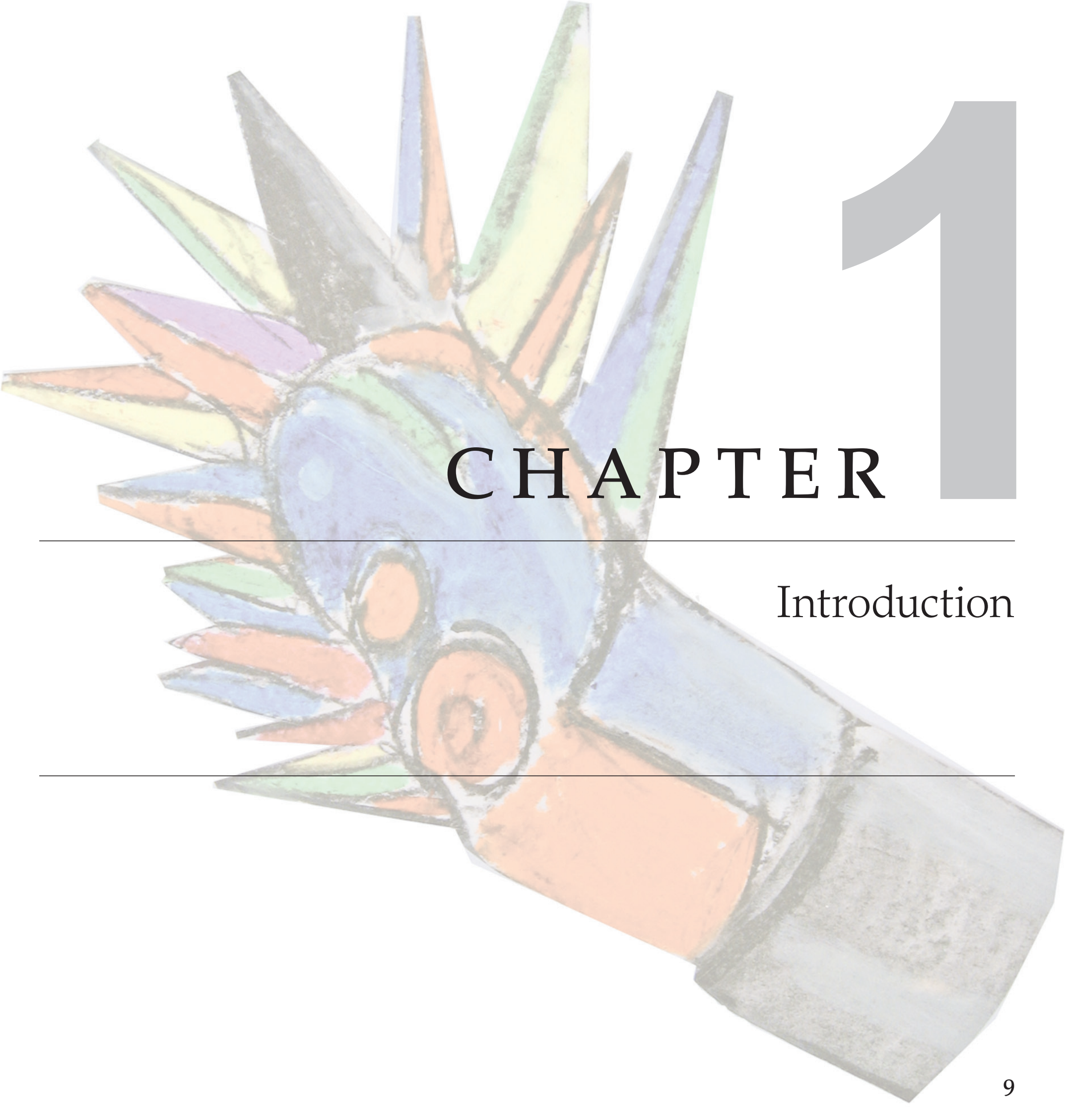
prof.dr. M.A. Cuesta

“For once you have tasted flight you will walk the earth with your eyes turned skywards, for there you have been and there you will long to return.”

Leonardo da Vinci, Italian engineer, painter, & sculptor (1452 - 1519)

Voor de toekomst

INDEX



CHAPTER 1

Introduction

Introduction

In the ongoing search to minimize surgical trauma, minimally invasive techniques such as the laparoscopic cholecystectomy have rapidly made headway over the last decade.

A laparoscopic approach has many advantages over conventional, 'open' surgery. Due to smaller incisions, fewer wound-infections are seen [1]. Patients report less operative pain and hospital stays can be shortened, with the effect of patients returning earlier to their daily activities [2]. Less incisional hernias are seen and cosmetics are better after laparoscopic surgery [3], an effect that seems to grow in importance in nowadays society. Even though laparoscopic training is a growing part of the surgical residency, major laparoscopic surgery is still restricted to devoted surgeons with extensive practice and expertise. Advanced laparoscopic surgery requires a great deal of skill and dexterity, mainly because of the technical difficulties emerging with this method.

These difficulties consist of unnatural eye-hand coordination, an unnatural working-axis, 2-dimensional vision, limited degrees of freedom and the 'fulcrum effect'. The fulcrum effect is the unnatural movement of laparoscopic instruments; while moving the handle of the instrument to the right outside the patient, its tip moves leftward inside the patient.

Robotic assistance may help to overcome these difficulties. Recent surgical robots restore natural eye-hand coordination and a natural working-axis. They use 3-dimentional vision and have no fulcrum effect. Furthermore, seven degrees of freedom are available, opposed to the 5 degrees of freedom in conventional laparoscopic instruments. These conventional instruments use horizontal movement, vertical movement, depth movement, rotation and opening- and closing of the instrument. Robotic instruments however, use a 'mini-wrist' at the tip of the instrument. This wrist can articulate horizontally and vertically, thus adding two more degrees of freedom (fig 1).

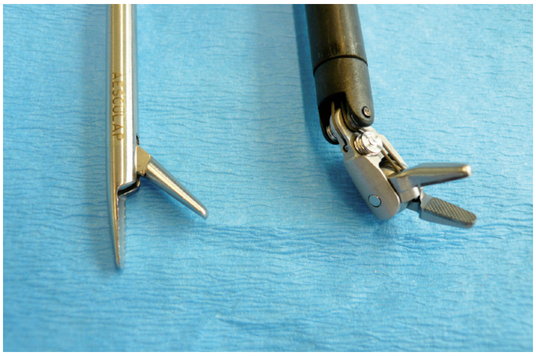


Fig 1: Robotic instrument with 7 degrees of freedom.

Nevertheless, current robotic surgical systems lack any form of haptic feedback, a feature which has been reported by several authors to be a major drawback [4 - 6]. Even so, with overcoming the abovementioned limitations of conventional laparoscopic surgery, robotic assistance may very well be of surplus value, especially in highly advanced laparoscopic procedures such as suturing a vascular anastomosis [7] (fig 2).

It seems to be this highly technical difficulty that is responsible for the lack of enthusiasm for laparoscopy among the vascular community. Several case-reports and patient-series have been published since 1993, when the first laparoscopy assisted aortobifemoral bypass for aortoiliac occlusive disease was described by Dion [8]. These pioneers report on several difficulties emerging when implementing laparoscopics in vascular surgery.

To begin with, obtaining a stable and safe operative field is essential. Several methods have been developed, three of which are commonly used. First, a retroperitoneal approach toward the abdominal aorta can be used [9, 10]. Using a small flank incision, through digitaldissection and subsequently using a dissection-balloon, access to the aorta can be obtai-ned.

A problem in this approach though, is the relatively small pneumoretroperitoneum that will easily collapse when suction is applied during surgery, thus leaving the surgeon without vision [10].

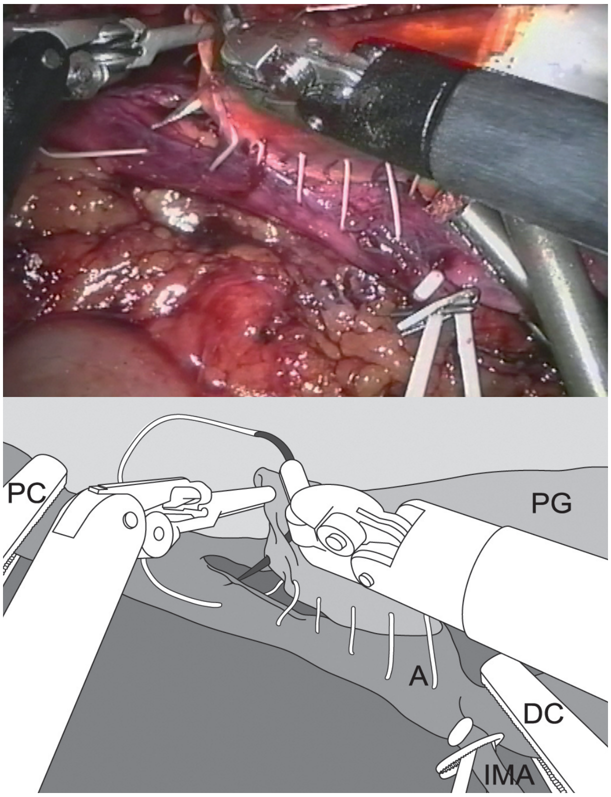


Fig 2: Robot assisted end-to-side anastomosis. PG: prosthetic graft; A: aorta; IMA: inferior mesenteric artery; PC, DC: proximal and distal aortic clamps.

A second approach is creation of an 'apron' from part of the peritoneum [11]. Through a transabdominal approach, a flap of the peritoneum is dissected and used to hang the bowels to the abdominal wall by means of transcutaneous stitches. This approach is time-consuming and tearing of the thin retroperitoneal flap results in an immediate loss of the surgical field and conversion to open surgery is necessary.

Finally, a method that uses extreme patient rotation (85 – 90°) – as described by Coggia [12] – can be used. This method uses an inflatable pillow positioned under the patients left flank. After tilting the operation table, the pillow is inflated and a maximum patient rotation is achieved (fig 3). Subsequently, a transabdominal approach is performed in which the left colon can be dissected. By use of gravity, the left colon falls down and can be kept in place with a fan-retractor, thus providing a stable operative field of the abdominal aorta.

A second problem of laparoscopic aortic surgery is creation of the aortic anastomosis. Due to the technical difficulty of this part, it seems to be reserved

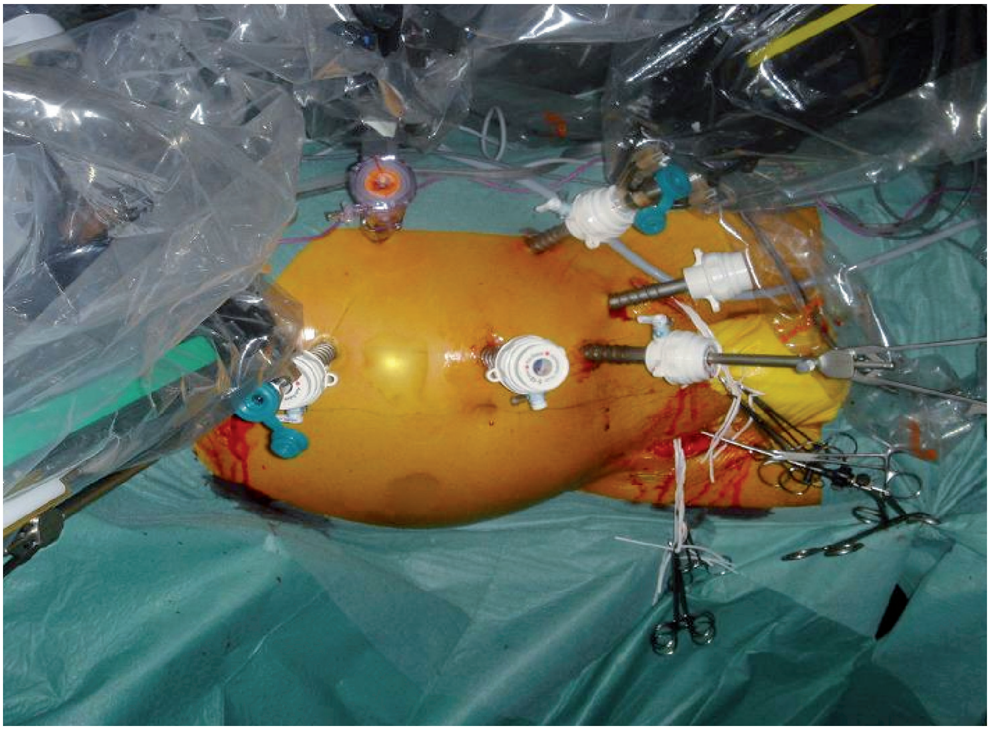


Fig 3: Maximum patient rotation (85 – 90°) during robot assisted laparoscopic aortobifemoral bypass.

for only a few experts around the world. With robotic assistance however, the bar may be lowered and this technique might be accessible to the more 'common' vascular surgeon.

Meanwhile, another minimally invasive approach in vascular surgery is rapidly gaining in popularity. Endovascular therapy is being applied by vascular surgeons around the world as a treatment for both occlusive and aneurysmal aortic disease [13, 14]. Nevertheless, long-term results of endovascular treatment are still not available and its applicability is limited by the anatomic suitability in aneurysmal – and the extend of occlusive lesion in aortic occlusive disease. (Robot assisted-) laparoscopic treatment is less bound by these limitations and a similar reconstruction as in open surgery is acquired, thus comparable results in long-term outcomes can be expected.

During the late 1980s and early 1990s, robotic surgical systems were developed with the main purpose to perform telesurgical procedures. Both NASA [15] and the US military funded several projects with the goal to achieve surgical robots, which could be controlled over a distance. Having a surgical robot on site at a

Fig 4: Zeus-AESOP system OR-setup.

frontline infirmary, surgeons would not have to risk the dangers of being close to the battle to perform surgery. In the same light, astronauts in outer space could be operated on without the need of a surgeon being physically present.

Fig 5: Zeus-AESOP system is controlled by surgeon from remote console.

As an offspring of one of these projects, a company called Computer Motion developed the Automated Endoscopic System for Optimal Positioning (AESOP). This AESOP consisted of a robot-arm, which could hold endoscopic equipment such as an endoscopic camera. The robotic arm was voice-controlled via a microphone and listened to pre-recorded voice-commands such as “AESOP, move left!” or “AESOP, stop!”. The surgeon had to record his voice onto a cartridge, so that the system would respond only to his/her voice.

Soon the AESOP system was extended with the Zeus surgical system (fig 4). This system consisted of two robotic arms, which could be mounted onto the operation table. The arms could be equipped with endoscopic instruments that at first had only five degrees of freedom, but with a next version, instruments with seven degrees of freedom were added.

Fig 6: da Vinci system during surgery.

The surgeon would take place behind a console and sit comfortably whilst using the handles to control the robotic instruments (fig 5). The latest model of the Zeus-AESOP system could be equipped with a 3-dimentional endoscopic camera, giving the surgeon a better dept perception. Meanwhile, another company was making headway in the field of roboticsurgery. Intuitive surgical had developed a robotic surgical system, which was similar to the Zeus-AESOP combination. The da Vinci surgical system (fig 6) is a robotic master/slave system, which consists of three parts. First the robotic arms (three at first, later models are equipped with a fourth arm) that are mounted on a cart. This cart can be positioned alongside the operation table to provide access to the patient and the operative field. One arm is to be equipped with the endoscopic camera, which holds a double lens (fig 7).

The separate images recorded from both lenses are displayed on two different monitors inside the surgical console, at which the surgeon looks separately with both eyes (fig 8). This way, a natural 3-dimensional sight is provided. The surgical console is the second part of the system and holds, besides the monitors, two handles to control the surgical instruments, five different pedals and a keypad to operate system functions. The pedals can be used to switch between instruments and camera and to focus the camera. They can also be used to 'clutch'

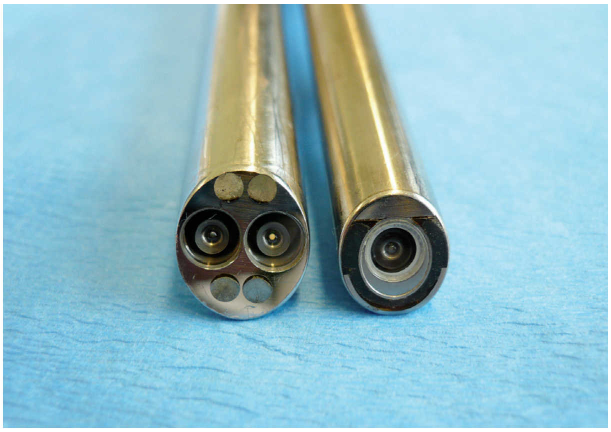


Fig 7: 3D endoscopic camera vs 2D endoscopic camera

Fig 8: One-on-one translation from console to instruments.

the handles; when pressed, the handles can be positioned ergonomically without moving the instruments. System functions contain motion scaling (1:3 and 1:5) and switching back and forth between the third and fourth arms in later models.

The third part of the da Vinci surgical system is a separated tower on which a second monitor is mounted. This tower also contains controlling switches for the light source and boxes thatare connected to a microphone inside the console. This way the surgeon can communicate with the surgical team without having to look up from the console.

In 2003, Computer Motions merged with Intuitive surgical and the company decided to no longer produce the AESO-Zeus system. Intuitive surgical has introduced several updates of the da Vinci surgical system since its first model. The latest model is the da Vinci S HD (fig 9). Most important changes are a motorized, more compact cart for the surgical arms mounted with an extra display on top. Furthermore, the endoscopic camera is equipped with high definition imaging. These latest models cost around € 1.490.000,= with a service contract of € 140.000,= a year. A robotic instrument costs about € 2.000,= average and can be used 10 times.
Over the last decade, robot-assisted surgery has been applied in many fields of surgery. Especially its fine controllable movements with increased accuracy can be of use when performing minimally invasive procedures, such as a beating heart coronary artery bypass graft (CABG) [16]. Other examples of robot-assisted procedures are: mitral valve repair in cardiac surgery, fallopian tube reconnection and hysterectomy in gynecology, pulmonary lobectomy, thymectomy and esophagectomy in thoracic surgery, prostatectomy and cystectomy in urology, donor-nefrectomy in transplant surgery and Roux-en-Y gastric bypass and Nissen fundoplication in general surgery [17 - 27].

In September 2001, Jaques Marescaux managed to successfully utilize a robotic system according to its original intention for use. 'Operation Lindberg' was the first trans-atlantic surgical procedure ever performed [28]. He used a Zeus-AESOP system, performing a cholecystectomy on a patient located in Strassbourg, France, whilst being seated behind a console in New York, USA; a distance of 14.000 kilometers. Main bottle-neck was the rate of data transfer; as previous studies showed, a time delay of < 700 ms has to be achieved in order for telesurgical procedures to be safe [29]. Using high-output fiberoptics, data transfer with a delay 80 ms was achieved. With an additional 70 ms for decoding of the video image, total time delay was 150 ms. The procedure was performed in 45 minutes, without any technical difficulties.
With this achievement, the feasibility and safety of robotic telesurgery was established. Nevertheless, whether its use can shortly be implemented in ways NASA and the US military had in mind remains to be seen. Due to huge costs and the necessity of surgical presence in the case of complications, this purpose of telesurgery seems to be unrealistic in the near future.

However, telesurgery can be used for tele-mentoring: a surgeon can be supervised by an expert-surgeon without the necessity of the expert-surgeon actually being at the same hospital [30 - 32]. He can supervise and comment on the procedure and even take over from his own console, if two systems are connected.

Fig 9: da Vinci S HD surgical system.

Another use of the robotic systems lies in the integration of 3D imaging [33, 34]. After making a 3-dimentional CT-scan of the patient, a reconstruction of the patient can be made. This reconstruction can be uploaded onto the robotic systems' computer and the surgeon can 'practice' a procedure on a patient prior to actually performing the operation. Furthermore, this reconstruction may be projected over the real-time image during the actual operation, helping the surgeon to identify certain structures or tumor-tissue [35] (fig 10). A safety-feature can be built in; for example, the robot can be programmed to refuse clipping the common bile duct during a cholecystectomy. These features predict a role for robotic surgical systems as a valuable asset during the surgical residency. The purpose of this thesis consists of determining the role of robotic assistance in aortic surgery. A minimally invasive alternative for this type of surgery, which – according to the gold standard – usually consists of maximally invasive abdominal surgery, may be beneficiary for patient outcomes.

Due to the technically demanding nature of conventional laparoscopic treatment in aortic disease, appliance of robotics may be helpful. In **chapter two** a comparison is made between laparoscopic instruments and a newly developed mechanical master-slave manipulator. This instrument consists of two purely mechanical instruments with two additional degrees of freedom at the instrument-tips, comparable to the instruments in robotic systems. It is examined whether extra degrees of freedom enhance the outcomes in basic laparoscopic training exercises, performed by inexperienced medical students.

Chapter three describes a study to determine the most appropriate suture-material to use in robotic surgery. During laboratory tests, it was noticed to be virtually impossible to construct a vascular anastomosis without manipulating the suture numerous times with the robotic instruments. Due to the lack of haptic feedback in robotic systems, it was hypothesized that some suture materials may be more susceptible to robotic manipulation then others. This could supposedly lead to loss of strength and subsequently compromise the integrity of the vascular anastomosis. A recommendation as to what suture-material to use in robotic surgery is given. After initiating robot assisted laparoscopic aortic surgery, performing five aortobifemoral bypasses with a Zeus-AESOP system that was on temporary loan, our institution acquired a da Vinci robotic surgical system. We expanded our series to a total of eight patients. Results of this early clinical experience are described in **chapter four**.
As we expanded our series to 17 patients, a significant shortening of aortic clamping time and anastomosis time was noted. We decided to perform a

comparative study between our first 8 and latter 9 patients, in order to determine whether a learning curve could be described. Intra-operative and post-operative data was evaluated and the effect of the learning curve is explained in **chapter five**.

In **chapter six**, we describe a case control study. A retrospective study was performed in order to identify a group of comparable patients who were treated for aortoiliac occlusive disease by means of conventional surgical methods. These patients were compared to our prospectively obtained database of 24 patients. We compared gender, age, body mass index, cardiovascular risk factors, ASA class and TASC type lesion to ensure patient groups were comparable. Intra-operative and post-operative data were evaluated in order to establish a possible added value of robot-assisted laparoscopy.

Chapter seven consists of a systematic review of laparoscopic aortic surgery. We identified patient series (n > 5) in which either laparoscopy-assisted -, hand-assisted laparoscopic -, totally laparoscopic -, or robot-assisted laparoscopic procedures were performed as a treatment for aortoiliac occlusive or – aneurysmal disease. A total of 30 series were identified and outcomes were compared.

Finally, because in chapter seven only a total of two series were identified in which robot-assisted laparoscopy was performed, we decided to carry out another systematic review. **Chapter eight** is a systematic review on robot-assisted laparoscopy in vascular surgery. A total of seven experimental - and clinical series were identified, performed with both the Zeus-AESOP and the da Vinci surgical system. Experimental and clinical outcomes were discussed.

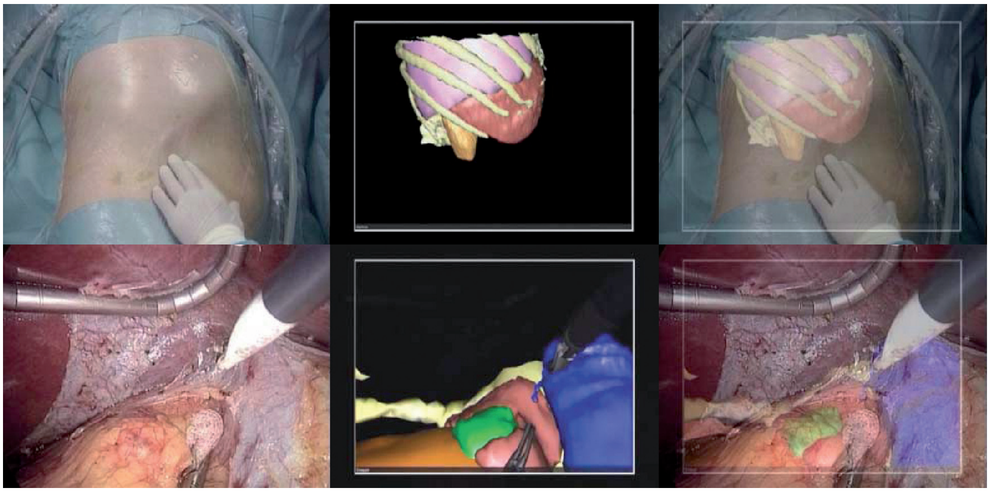


Fig 10: Augmented reality combining in-operation image with scanned images.

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CHAPTER 2

The mechanical master-slave manipulator: an instrument improving the performance in standardized tasks for endoscopic surgery.

Diks J, Jaspers JE, Wisselink W, de Mol BA, Grimbergen CA.

Surg Endosc 2007;21:1025-31

Abstract

Background: To evaluate the feasibility and efficacy of a mechanical minimal invasive manipulator (MIM) for endoscopic surgery. The MIM consists of two purely mechanical, hand-controlled endoscopic arms with joints, which allow 7 degrees of freedom (DOFs).

Methods: 30 medical students performed 4 different tasks in a pelvic trainer box. with two conventional endoscopic needle holders or with a set of MIMs. The exercise consisted of 4 different tasks: repositioning coins, rope-passing, passing a suture through rings and tying a surgical knot. All experiments were recorded on videotape (S-VHS) and data was analysed afterwards by an independent observer using a quantitative time action analysis.

Results: A significant difference between numbers of total actions (including failures) was shown in most exercises in favour of the MIM-group. A significant difference in failures per task was shown in favour of the MIM-group as well. There was no significant difference shown in matter of total time per exercise.

Conclusions: These tasks clearly demonstrated the efficacy of the MIM, even though some technical flaws emerged during the experiments. Considering the fact that a first prototype of the MIM was tested, modifications are to be expected in a next model. These experiments show the potential of the MIM and it is expected to be a competitive and economical instrument for endoscopic surgery in the near future.

Introduction

The purpose of endoscopic surgery is to reduce surgical trauma to patients, resulting in less operative morbidity, faster recovery, and reduction in costs [1, 17]. Recently introduced robotic surgical systems have facilitated complex endoscopic surgery, such as micro-anastomoses in coronary artery bypass grafting [10, 12] and aortic anastomosis [13, 20]. These systems were designed to translate the surgeon's hand movements to the tip of the endoscopic instrument in a remote operative field, using a computer assisted Master-Slave system (figure 1).
Advantages of these systems are the 3D visualisation and the inclusion of a "wrist" at the end of the instruments, providing articulated motion in 7 degrees of freedom (DOFs): three translations, three rotations and the opening/-closing action [7]. The wrist movements of the surgeon's hands are translated to the movements of the instrument tip, maintaining the same spatial relation.

However, these robotic systems still have considerable limitations. They are large and bulky and they are expensive. Another limitation of these systems is

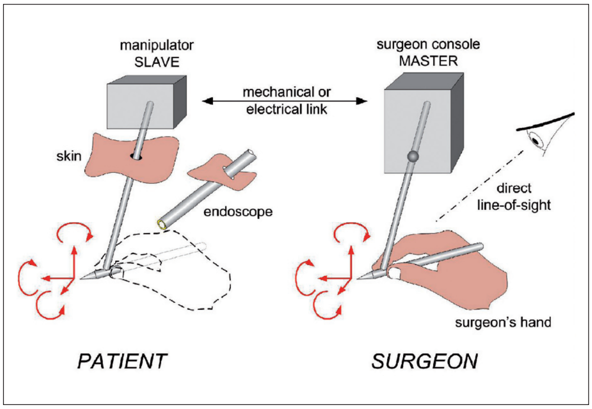


Fig 1: Schematic master–slave system. The instrument tip and the surgeon's handle has six degrees of freedom in positioning. With a kinematic coupling between the handle and the tip, the instrument tip moves exactly in the same direction as the handle. This kinematic link can be implemented electronically (using sensors, actuators, and the like), as with robotic devices, or mechanically (using push bars, pulleys, and the like), as with a mechanical manipulator (picture by Mark Wentink).

the lack of force feedback [2, 5, 14]. The feedback from the operation field consists of visual information only. Lowering the costs and making the system more manageable are mandatory for these systems to become a standard tool for endoscopic surgery.

In an attempt to overcome some of the above mentioned limitations of robotic systems, a minimally- invasive manipulator (MIM) was developed. The MIM is a small, economical and mechanical alternative for robotic surgical systems. It consists of a balanced parallelogram mechanism on which a deflectable endoscopic instrument is attached at one end and at the other end a surgeon's handle. Instead of an electrical link, the instrument and handle are connected by a mechanical link in such a way that movement directions of the handle correspond to identical movement directions of the instrument tip in 7 DOFs.

In addition, with a set of two of these devices, the two handles have the same spatial orientation relative to each other as the instrument tips and therefore can be manipulated by the surgeon in an intuitive and ergonomic way (figure 2 and 3). First phantom experience indicated that the system functions properly and that suturing is feasible [9]. To test whether working with the MIM is indeed more intuitive and the extra DOFs are advantageous to working with conventional endoscopic instruments, it was necessary to define simple and reproducible manipulation experiments in which these extra functionalities would play a role. These experiments were subsequently used to compare manipulation with conventional endoscopic instruments to working with the MIM.

Methods and Materials

30 medical students, all without any surgical experience, performed four different experiments in a trainer box. Defined actions and failures per experi-

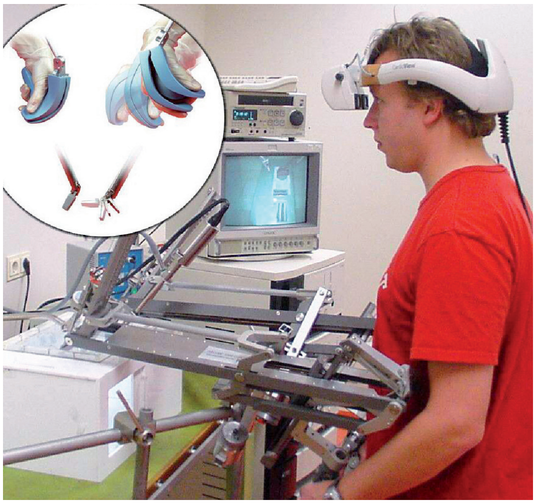
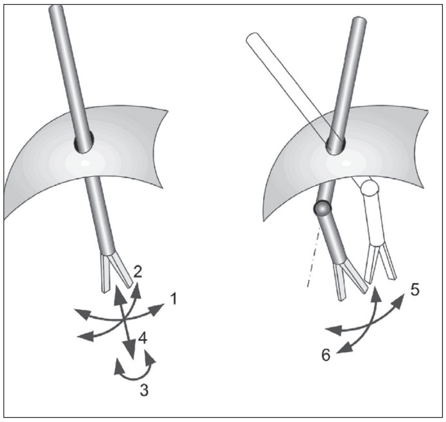


Fig 2: The mechanical manipulator in the experimental setup. The picture shows two parallelogram mechanisms coupled to the table rail. The inset shows that movement directions of the handle correspond to identical movement direc-tions of the instrument tip in all degrees of freedom.

ment are presented in table 1. The participants were randomized to perform the experiments either with two conventional endoscopic needle holders (Karl Storz, Tuttlingen, Germany) or with a set of MIMs. All experiments were performed with the instruments positioned in the same orientation to the target area for both groups.

The endoscope was positioned in a holder (Passist) [8] in between the instruments, parallel to the surgeon's natural line of sight [19]. A 10mm 0° stereoscopic endoscope and 3-D camera (Carl Zeiss Ltd., Oberkochen, Germany) in combination with a Cardio View Head-Up-Display (HUD) (VISTA Medical Technologies, Inc., Carlsbad, CA, USA) (figure 3) was used in all experiments to provide the subjects with a stereoscopic image, which is claimed to be beneficial when using instruments with additional degrees of freedom [7]. Before starting each experiment, the participants had a one minute period to become familiarized with the setup.

Fig 3: Conventional endoscopic instruments (left) have four degrees of freedom (DOF): two rotations around the incision in the skin (DOF 1 and 2), the rotation of the instrument around its axis (DOF 3), and the in-out translation of the instrument (DOF 4). By adding two extra DOF (right) (DOF 5 and 6), the orientation of the instrument tip can be varied independently from the instrument shaft, enabling the surgeon to approach the tissue from different directions. The opening and closing of the instrument is the seventh DOF (picture by Mark Wentink).



Experiment 1: repositioning coins.
This was a simple pick and place experiment. A 1-Eurocent coin had to be taken out of a receptacle with the left-hand instrument. The coin was to be presented to the right-hand instrument and subsequently the subject was to put the coin into a second receptacle.

This sequence of picking up, passing over and dropping was repeated two times. Consequently, the same order of sequences was repeated, starting with the right-hand instrument. Unintentional or incorrect dropping of a coin was counted as a failure. The number of defined actions was counted and the total time was recorded from picking up the first coin to dropping the last coin into the last receptacle.

Experiment 2: rope-passing
In this experiment the two instruments had to work together during manipulation. A marked rope (25 x 0.3 cm) had to be alternately grasped with the left and the right instrument at indicated points, while keeping the rope above the floor of the training box. The rope was fastened at both ends and had 11 predetermined, marked grasping points. The rope had to be passed-through twice, once grasping the rope with both instruments on the same (left) side and once grasping the rope on both sides, on the right side with the right instrument and on the opposite (left) side with the left instrument. Grasping without touching the rope, grasping the printed lines in between the marked areas or dropping the rope was counted as a failure. Time from picking up the rope to total run-through was recorded and the number of defined actions was counted (figure 4).

Experiment 3: passing a suture through rings
The purpose of this task was to pass a surgical needle with a piece of suture (Prolene® 4-0) through eight rings, following a preindicated direction. Failures were determined as dropping the needle, 'floating' the needle in a ring without grasping it, grasping without touching the needle, not following the indicated direction, missing the ring with the needle-point and passing the ring only halfway. Total number of actions and the time from first grasping the needle to totally passing the last ring was recorded (figure 5).

Experiment 4: tying a surgical knot
A suture (Vicryl® 3-0) was used to tie a surgical knot, consisting of one knot using two forward loops followed by one knot using a backward loop. The scored

Fig 4: Experiment 2: Band-passing, manipulating a marked band with two instrument by grasping it at the same side (minimally invasive manipulator experiment).

failures were 'mislooping' the suture, grasping without touching the suture and pulling the suture without passing the loop. Total number of actions as well as total time necessary to complete the task was recorded.

Analysis

All experiments were recorded on videotape (S-VHS) and data was analysed afterwards by an independent observer using a quantitative time action analysis to determine the efficacy, counting the actions and the time needed per task. Failures were counted as a measure for efficiency. A quantitative time-action analysis was performed through which a measure of efficiency in time and actions was determined. Table 1 shows the definitions for actions and failures per experiment.

Statistical analysis was performed using SPSS 12.0.1 for Windows tm. A Mann Whitney U test was used to compare differences between both methods. Data shows medians of time and actions with the according range. A p-value of < 0,05 was considered statistically significant.

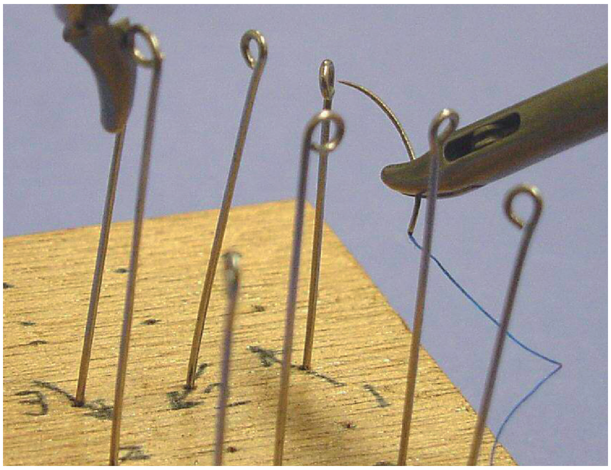


Fig 5: Experiment 3: Passing a suture through rings, following a predefined path (laparoscopic experiment).

Results

All participants successfully completed the experiments, although there were problems with 6 participants in the MIM-group, doing the knot-tying experiment (see Discussion).

Table 1

Actions/failures:	Definitions:
Coins:	
Grasping coin	Grasping a coin
Lifting coin	Elevate coin from receptacle
Transferring coin	Move coin towards next receptacle
Hand over coin	Hand over coin from one instrument to the other
Dropping coin	Dropping coin correctly into receptacle
Unintentional dropping coin	Unintentional dropping coin during exercise
Incorrect dropping coin	Dropping coin outside receptacle or into wrong receptacle
Rope:	
Grasping rope	Grasping the rope on correct place
Dropping rope	Dropping rope
Misgrasping rope (out place)	Grasping rope, but on wrong place
Misgrasping rope (no rope)	Grasping without touching rope
Rings:	
Grasping needle	Each grasping of the needle or suture during exercise
Passing ring	Passing a ring
Dropping needle	Dropping the needle during exercise
Floating needle	Dropping needle while passing ring; needle doesn't fall, but hangs in the ring
Misgrasping	Grasping without touching the needle
Wrong direction	Passing a ring in wrong direction
Missing ring	Moving towards ring without passing it
½ Passing	Passing the ring halfway and subsequently taking the needle back from ring
Knot:	
Making loop	Making a loop with the suture
Grasping suture	Grasping the suture
Pull through	Pulling the suture through the loop
Mislooping	Making a loop without success
Misgrasping	Grasping without touching the suture
Mispulling	Pulling the suture without passing the loop

table 1: Definitions of actions and failures for all exercises

Table 2

	Laparoscopy (n = 15)		**MIM** (n = 15)		
	time	range	time	range	p-value
Coins	301	126 - 622	339	151 - 600	NS
Rope	393	183 - 890	349	144 - 581	NS
Rings	704	407 - 1320	814	506 - 1529	NS
Knot	211	68 - 804	237 (n = 9)	128 - 1395	NS

table 2: Time (s) per exercise necessary to complete exercise (median)
NS: not significant

Table 3

	Laparoscopy (n = 15)		**MIM** (n = 15)		
	actions (n)	range	actions (n)	range	p-value
Coins					
Grasping coin	10	6 - 18	7	6 - 13	0.01
Lifting coin	9	6 - 16	6	6 - 13	0.01
Transferring coin	8	6 - 16	6	6 - 13	0.03
Hand over coin	9	6 - 18	6	6 - 14	0.04
Dropping coin	6	6 - 6	6	6 - 6	NS
Failures	5	1 - 12	1	0 - 8	< 0.001
total (incl. failures)	48	32 - 86	32	30 - 67	< 0.001
Rope					
Grasping rope	22	20 - 36	21	21 - 23	NS
Failures	10	3 - 29	1	0 - 8	< 0.001
total (incl. failures)	35	24 - 64	23	21 - 31	< 0.001
Rings					
Grasping needle	38	22 - 99	30	25 - 45	0.03
Passing ring	8	8 - 8	8	8 - 8	NS
Failures	21	10 - 101	16	5 - 31	NS (0.068)
total (incl. failures)	67	44 - 208	55	40 - 82	0.02
Knot			(n = 9)		
Making loop	6	3 - 10	6	3 - 21	NS
Grasping suture	2	2 - 6	2	1 - 15	NS
Pull through	2	2 - 2	2	0 - 3	NS
Failures	6	0 - 20	3	0 - 35	NS
total (incl. failures)	15	7 - 35	10	6 - 73	NS

table 3: Number of actions necessary to complete exercise (median)
NS: not significant

Tables 2 - 3 show the results of the time-action analysis. Table 2 shows the median time and range needed per experiment to complete the task. There was no statistical significance shown in time needed to complete each exercise. In table 3, median actions and range needed per experiment are shown per action, as well as the median failures and range per experiment. Table 3 and figure 6 show the median total of actions (including failures) and range needed per experiment. There were significantly less actions recorded in the MIM group for all exercises, except for the knot-tying experiment.
Subanalysis of the different exercises showed that grasping actions were significant less in the MIM-group in the Coins exercise (exp. 1) and Rings exercise (exp. 3): median 7, range 6 - 13 vs. median 10, range 6 - 18 ($p = 0.01$) and median 30, range 25 - 45 vs. median 38, range 22 - 99 ($p = 0.03$). Failures were shown to be significantly less in the MIM-group in the Coins exercise (exp. 1) and Rope exercise (exp. 2) median 1, range 0 - 8 vs. median 5, range 1 - 12 ($p < 0.001$) and median 1, range 0 - 8 vs. median 10, range 3 - 29 ($p < 0.001$). In the Rings and the Knot experiments, no significant difference in failures was shown, although a trend was shown in the Rings experiment in favour of the MIM-group; median 16, range 5 - 31 vs. median 21, range 10 - 101 ($p = 0.068$).

Discussion

Endoscopic techniques are used for multiple surgical procedures, which mainly consist of resection tasks (such as cholecystectomy in general surgery). The design of endoscopic instruments was initially based on conventional surgical tools; they are long and have only four DOFs in positioning (figure 3). These straight instruments have to pivot about a point of incision through the abdominal wall, which introduces a mirroring and a variable scaling of the hand movements controlling the tip of the instrument. This has to be compensated for by the surgeon (scaling and fulcrum effect) [4].

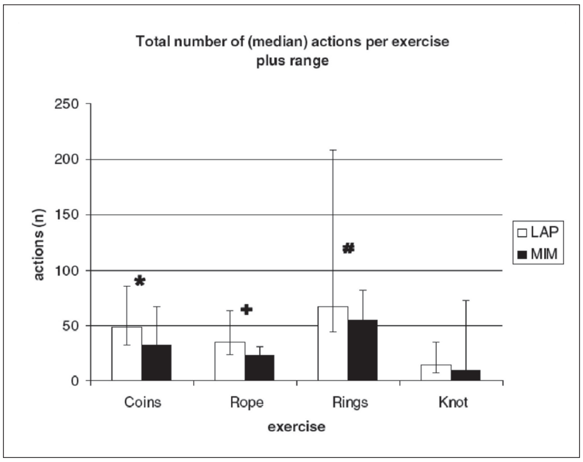


Fig 6: Total number of (median) actions per exercise plus range.

With conventional endoscopic instruments and their limited number of DOFs in positioning, it is impossible to approach the tissue from different directions (figure 3)and therefore it is almost impossible to perform delicate and complex surgical actions. The handles of these long instruments force the surgeon to use his hands in an unsupported and unnatural posture with a large distance to each other. The ergonomic quality of laparoscopic instruments is relatively poor [3, 18]. Due to the length and the orientation of these instruments, the surgeon often has to operate in an uncomfortable posture with extreme wrist positions.

Furthermore, vision is two-dimensional; the image of an endoscopic camera is projected on a monitor. Largely due to these characteristics, the learning curves of MIS are long and steep [11, 16] and especially in complex procedures its applicability has not yet been widely embraced. In order to overcome various limitations in endoscopic surgery, robotic surgical systems have recently been introduced. These systems overcome problems such as difficult control, poor ergonomics, a poor view (2D) and limited DOFs in manipulation and other surgical tasks. Although it seems these robotic surgical systems have their advantages and various series have been reported in which these systems have been successfully applied for clinical purposes [6, 15], its disadvantages are not to be taken lightly. The systems are large and bulky, making them uncomfortable to move around in the operating room. Furthermore, the systems are expensive, both in purchase as in maintenance. These systems do not provide any force feedback, making the surgeon dependent of visual information only.

The MIM is a passive mechanical endoscopic instrument with the same DOFs as robotic systems, but with force feedback. When compared to conventional endoscopic instruments, the MIM improves the ergonomics for the surgeon, enabling him to position his hands in a natural orientation to each other, providing improved eye-hand coordination, intuitive manipulation and an ergonomic posture. The conducted experiments were designed as simple tasks that can be executed in both groups, mainly due to the level of inexperience of our participants. They had to carry out the experiments with no surgical/-endoscopic experience what so ever, to prevent a bias in the learning curve due to experience either in laparoscopy or robotic surgery. The experiments, however, were representative and resembled experiments used in the residents program for endoscopic surgery.

The set of MIMs was a first set of prototypes, and it was technically not yet perfected. During testing, technical flaws emerged, which will be corrected in a next prototype. The handles were noted not to be positioned quite favourably, which led to an additional amount of failures, such as dropping the needle in experiment 3. Furthermore, one of the MIMs showed excessive friction in one degree of freedom (in-out), which made it harder to manipulate in a small range, such as experiment 3.

In the knot tying experiment, another flaw of design was noted; 6 participants endured trouble in sliding a loop from one of the instruments. The joints at the tip of the instruments are not protected in the design, making it an easy trap for a piece of suture to get caught in. This happened in 6 of the 30 cases and it showed to be nearly impossible to get the suture out without damaging it (figure 7). The above-mentioned observations were very enlightening and will most certainly be considered in building a new set of prototypes.

Even with the above-mentioned limitations of the MIM, it is shown that an additional number of DOFs in an endoscopic instrument is favourable. Although there was no difference in time in the experiments, there was a significant difference in the amount of actions and failures in the first 3 experiments. In the laparoscopy group, extra regrasping actions were needed to reposition the coin, rope or needle inside the grasper tips to be able to fulfil the exercises, leading to extra failures as well. The extra DOFs in the MIM group facilitated the exercises, because the coins, rope and rings were accessible from different angles. As a result, the participants needed less actions and had a smaller number of failures when compared to the laparoscopy group. Considering the modifications that are to be expected in a next set of MIMs, it has been shown that the instrument has potential. By comparing the MIM with robotic devices in a experimental or clinical setting, it is expected to be a competitive and economical instrument for endoscopic surgery in the near future.

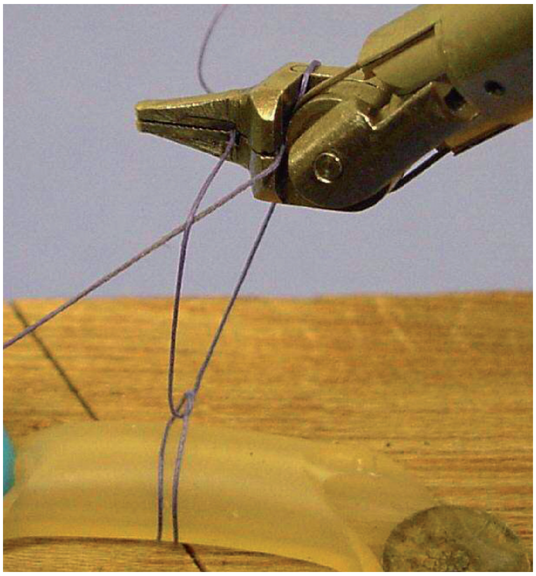


Fig 7: Experiment 4: Knot tying. A complication in this exercise is that with the minimally invasive instruments, the suture is caught in the grasper mechanism.

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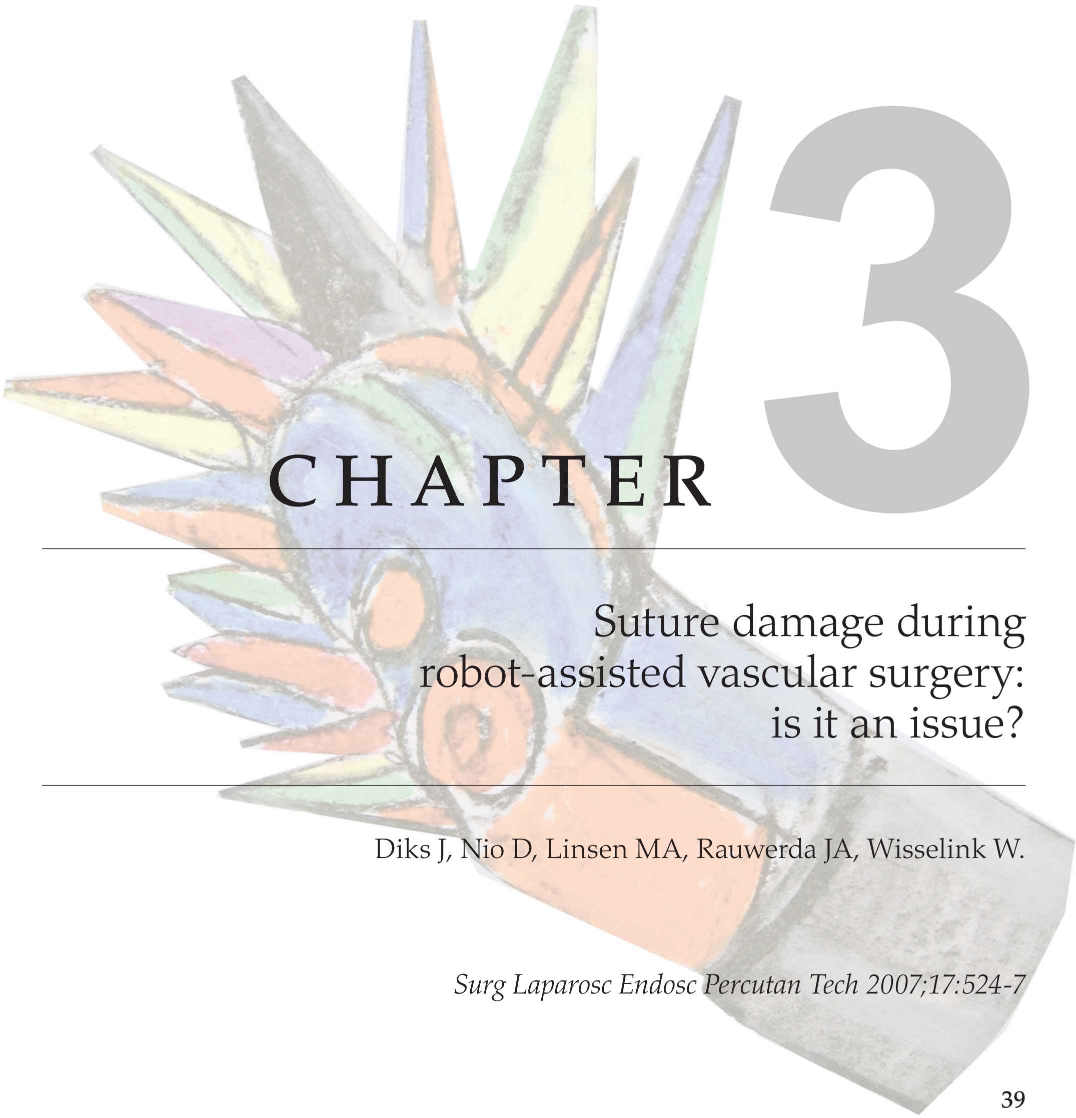


CHAPTER 3

Suture damage during robot-assisted vascular surgery: is it an issue?

Diks J, Nio D, Linsen MA, Rauwerda JA, Wisselink W.

Surg Laparosc Endosc Percutan Tech 2007;17:524-7

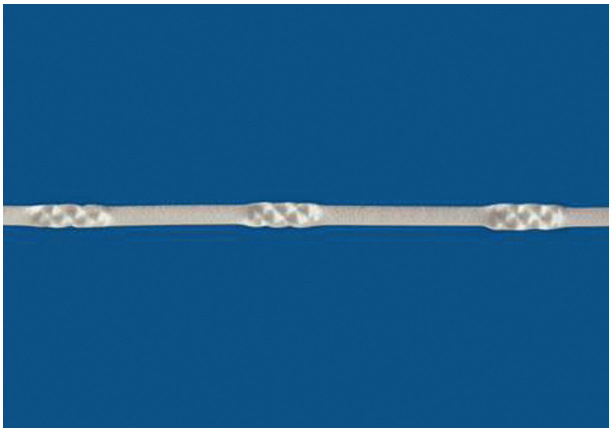
Abstract:
Background: Manipulation of sutures during endoscopic surgery could lead to damage of suture structure, supposedly resulting in loss of strength. Lack of tactile feedback in robotic surgical systems might increase this problem. The objective of this study is to evaluate suture strength after robotic manipulation and to determine which suture material is least susceptible to damage from robotic manipulation.
Methods: The da Vinci® surgical system was used to manipulate sutures. Three different suture materials (Prolene, ePTFE, Ethibond) of three different sizes (3-0, 4-0, 5-0) were tested. A total of 270 sutures were pulled on a Servohydraulic Universal Testing Machine. The frequency of breaks at a manipulation-point and the maximum applied force (N) before the suture broke were used for statistic analysis.
Results: No loss in strength was shown in the ePTFE sutures after manipulation, whereas both Prolene and Ethibond sutures showed a significant loss of strength.
Conclusion: ePTFE sutures are least susceptible to robotic manipulations and are therefore to be considered as a material of first choice.

Introduction:
Over the last decade, laparoscopic vascular reconstruction has become available as a minimally invasive option in aorto-iliac surgery for both occlusive disease and aneurysm repair. Various authors have reported their experience with laparoscopic vascular reconstruction [1 - 4] and have shown it to be a feasible but challenging technique. The use of surgical robots facilitates laparoscopic suturing and knot-tying [5], thus overcoming technical difficulties and long learning-curves of laparoscopic creation of vascular anastomosis.

However, in our experience with robot assisted laparoscopic surgery (RALS) for vascular procedures, it was impossible to hold the traditional rule not to touch sutures with surgical instruments. The suture had to be grasped and pulled for aligning or tightening. We noticed on several occasions that this manipulation resulted in a macroscopic change of structure of the used sutures (figures 1 and 2). Some sutures even broke during knot-tying.

In laparoscopic surgery, a combination of both visual and tactile feedback enables the surgeon to control the amount of force applied to a suture. In RALS however, the surgeon is dependent on visual feedback only, since robotic systems lack any type of tactile feedback [6 - 8]. As a result, the amount of applied force in grasping or pulling a suture is nearly impossible to control. The objective of this

Fig 1: Example of damaged suture (ePTFE CV-4) after manipulation with da Vinci surgical system (40 x magnification)



study was to investigate to what extent suture strength is jeopardized by robotic manipulation and whether a difference in endurance can be observed using different types of suture material.

Material and Methods:

Three different types of suture material were tested: monofilament polypropylene (Prolene™, Ethicon Inc., Johnson and Johnson Int., Somerville, NJ, USA), expanded polytetrafluoroethylene monofilament (ePTFE, Gore-Tex®, GORE, W.L. Gore & Associates, Inc., Flagstaff, AZ, USA) and polybutylate coated polyester (Ethibond®, Ethicon Inc., Johnson and Johnson Int., Somerville, NJ, USA).

Of each material, three different sizes were used (Prolene 3-0, 4-0, 5-0; Ethibond 3-0, 4-0, 5-0; ePTFE CV-3, CV-4 and CV-5). Manipulation consisted of grasping the sutures and was performed with a da Vinci® Surgical System (Intuitive Surgical inc., Sunnyvale, CA, USA), equipped with a Large Needle Driver (Endowrist®, Intuitive Surgical inc., Sunnyvale, CA, USA). One of the authors - a certified vascular surgeon (DN) - performed all manipulations with the same strength and duration,

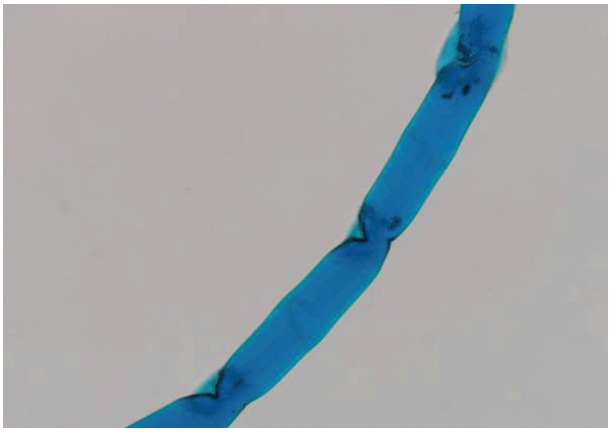


Fig 2: Example of damaged suture (Prolene 4-0) after manipulation with da Vinci surgical system (10 x magnification)

making it comparable to the manipulation that occurs during the actual construction of a vascular anastomosis. One set of sutures was grasped 10 times at different points, each one centimeter apart. Another set of sutures was grasped three times at the same point. A third set of sutures served as a control (no manipulation). A total of 270 sutures was tested.

All sutures were tested on a Servohydraulic Universal Testing Machine (SUTM) (Instron®, Canton, MA, USA), equipped with a 250 N sensitive head (figure 3). The sutures had a length of 30 centimeters, of which the proximal and distal 9 centimeters were used to fixate the suture onto the SUTM. Fixation was performed using a set of small clamps attached to the SUTM, thus obtaining standar-dization and making actual knot tying unnecessary.
Sutures were pulled on the SUTM with a permanent speed of 0.25 millimeters per second, building up force until the suture broke. The maximum force (N) applied depended on the resistance/strength of the suture and was measured. In addition, it was documented whether the suture broke at the fixation-point (FP; a point where the suture was fixated at the SUTM) or at a manipulation-point (MP; a point where the suture was manipulated).
Statistical analysis was performed using a Mann Whitney U test for the maximum force applied to the sutures and a Chi-square test was used to determine significant difference in breaking points. The tests were performed with SPSS 12.0.1 for Windows™. A p-value of ≤ 0.05 was considered statistically significant.

Fig 3: Servohydraulic Universal Testing Machine (SUTM)

Results:

270 sutures were tested. No suture broke directly during robotic manipulation. All control sutures (n = 90) broke at the fixation point. Manipulated sutures (n = 180) broke significantly more frequent at a manipulation-point.

No significance was demonstrated between 3 manipulations at the same point or 10 manipulations at different points for all suture materials. When comparing the suture size of each material, suture size did not influence the frequency of suture breaks at manipulation points. In the group that was manipulated 10 times, no predilection for breakage was shown in any part of the suture (proximal, middle or last part).

Tables

	control	10 manipulations at	p-value	3 manipulations	p-value
	n = 10	different points		at same point	
		n = 10		*n = 10*	
Prolene 3-0	0	6	0.003	5	0.010
Prolene 4-0	0	6	0.003	6	0.003
Prolene 5-0	0	7	0.001	5	0.010
ePTFE CV-3	0	1	NS	3	NS
ePTFE CV-4	0	2	NS	3	NS
ePTFE CV-5	0	3	NS	0	NS
Ethibond 3-0	0	10	< 0.001	10	< 0.001
Ethibond 4-0	0	7	0.001	10	< 0.001
Ethibond 5-0	0	10	< 0.001	10	< 0.001

table 1: Frequency of rupture at manipulation point and statistical significance
NS: Not significant

	control *n = 10*	10 manipulations at different points *n = 10*	p-value	3 manipulations at same point *n = 10*	p-value
Prolene 3-0	**21.5** (19.0 - 23.7)	**18.8** (16.9 - 22.4)	NS	**18.0** (16.2 - 21.3)	< 0.001
Prolene 4-0	**13.8** (11.4 - 14.6)	**11.7** (9.4 - 13.8)	NS	**12.0** (9.8 - 13.1)	< 0.01
Prolene 5-0	**6.9** (2.8 - 8.8)	**4.3** (0.4 - 8.3)	NS	**6.0** (3.3 - 7.9)	NS
ePTFE CV-3	**24.3** (21.5 - 25.2)	**23.8** (22.1 - 25.6)	NS	**23.5** (22.5 - 25.8)	NS
ePTFE CV-4	**14.8** (11.1 - 22.8)	**14.4** (12.2 - 14.8)	NS	**14.2** (10.7 - 15.5)	NS
ePTFE CV-5	**14.3** (11.7 - 16.0)	**14.0** (13.0 - 15.6)	NS	**13.7** (10.5 - 15.1)	NS
Ethibond 3-0	**36.6** (36.2 - 36.9)	**36.0** (35.7 - 36.6)	< 0.001	**35.1** (34.6 - 36.0)	< 0.001
Ethibond 4-0	**22.6** (20.8 - 23.4)	**21.9** (20.0 - 22.3)	< 0.01	**20.7** (20.0 - 22.4)	< 0.001
Ethibond 5-0	**9.3** (9.2 - 9.4)	**8.8** (8.1 - 9.0)	< 0.001	**8.9** (8.5 - 9.1)	< 0.001

table 2: Applied force (N) and statistical significance
NS: Not significant

Manipulated ePTFE sutures broke significantly less frequent at the manipulation-point compared to both Prolene (13 vs 35, $p < 0.001$) and Ethibond (12 vs 57, $p < 0.001$) (table 1). When strength was analized, ePTFE sutures showed no significant loss in strength. Prolene showed to be weakened after 3 manipulations at the same point in the 3-0 and 4-0 sizes (resp $p < 0.001$ and $p < 0.01$). Ethibond sutures were significantly weakened after robotic manipulation in all sizes ($p < 0.001$) (table 2).

Discussion

In endoscopic surgery when making intracorporeal anastomoses, the dogma to never grasp a suture with surgical instruments is not as strictly applied as in open surgery. In our experience with robot assisted laparoscopic surgery (RALS), we have noticed that grasping the suture during creation of a vascular anastomosis is inevitable. The total lack of tactile feedback in the current available robotic surgical systems and observation of sutures breaking during previous reported procedures [9], made us believe it could be hazardous to manipulate the suture during intracorporeal suturing and knot-tying [5, 10, 11].

Although various series have been reported in which robot-technology has been used to make a laparoscopic anastomosis [4, 9, 12 - 14], there does not seem to be a general consensus about the suture-material; both Prolene and ePTFE sutures are used in (robot-assisted) laparoscopic vascular surgery [3, 4, 9]. Ethibond sutures were added to the experiment to offer a possible alternative to the traditional vascular sutures because of its superior strength and its use in robotic cardiac surgery [15].

From our experience we noticed that sutures were grasped at different points during the beginning of the anastomosis to tighten the suture, whereas repetitive grasping at one particular point was seen during knot tying. To simulate and evaluate these different kinds of damage, the sutures were manipulated in different fashions; one set was manipulated 10 times at the different places, while another set was manipulated 3 times at the same spot.

During this study, the breaking-point was assumed to be the weakest point of the suture and the force/damage at the fixation point (FP) similar in each suture. Sutures breaking at the FP were considered to be less susceptible to robot-manipulation in comparison to sutures breaking at a manipulation point (MP), the latter illustrating that robotic manipulation had weakened the suture at that particulate point.

Both the group of 10 manipulations and the group of 3 manipulations showed an equal breaking-percentage at a manipulation point. This indicates that both types of trauma (recurring at one point or at different points) can be equally crucial to the suture's integrity. One can assume that repetitive manipulation, either at different points or at the same point, increases the risk at severe suture damage.

Macroscopically, damage was seen in most manipulated sutures. At closer range, the 'damage' seen in the ePTFE sutures consisted of indentations (figure 1). ePTFE sutures are filled with air. When manipulated, air is pressed out. This is macroscopically observed as 'damage', while the integrity of the material has not been affected.
In Prolene sutures, on the other hand, fibers were 'cut' during manipulation, causing severe damage to the integrity of the thread (figure 2). A similar problem occurred in the Ethibond group. These sutures consist of several filaments and are possibly more susceptible to robotic manipulations, because several filaments can be damaged at once, at the same manipulation point.

Suture-breaking during vascular surgery complicates completion of the anastomosis, resulting in longer cross-clamping and total procedure time. Moreover, loss of suture strength might even affect the quality and strength of the anastomosis itself. This could very well cause complications such as anastomotic leakage or development of a false aneurysm.
The amount of force that is applied with the robotic surgical system is very difficult to control, because of the total lack of tactile feedback. This implies that each manipulation applies a different - uncontrollable - force and therefore a different amount of damage to the suture, but proper research to evaluate this statement has yet to be performed.
Implementation of tactile feedback in robotic surgical systems is in development [16 - 18] but remains both technically and financially challenging. Another future solution could be a vascular stapler, which might replace a suture-sewn anastomosis all together [19, 20].
While these solutions are in development, an easier step in preventing suture breaks after manipulation in RALS should be the choice of the most appropriate suture material; a material that can be ´safely´ manipulated with a minimal risk at suture-breaks seems very important.

In conclusion, this study proved that Prolene sutures are quite susceptible to robotic manipulation and therefore should be reconsidered as a material of first

choice in robot-assisted vascular surgery. Ethibond demonstrated to be a material with good longitudinal strength compared to the other tested materials.
However, it showed to be less trustworthy after robotic manipulation. Test results showed ePTFE to be the suture material that is the least susceptible to robotic manipulation. In our opinion this is the most reliable suture to use in robot-assisted laparoscopic creation of intracorporeal vascular anastomoses.

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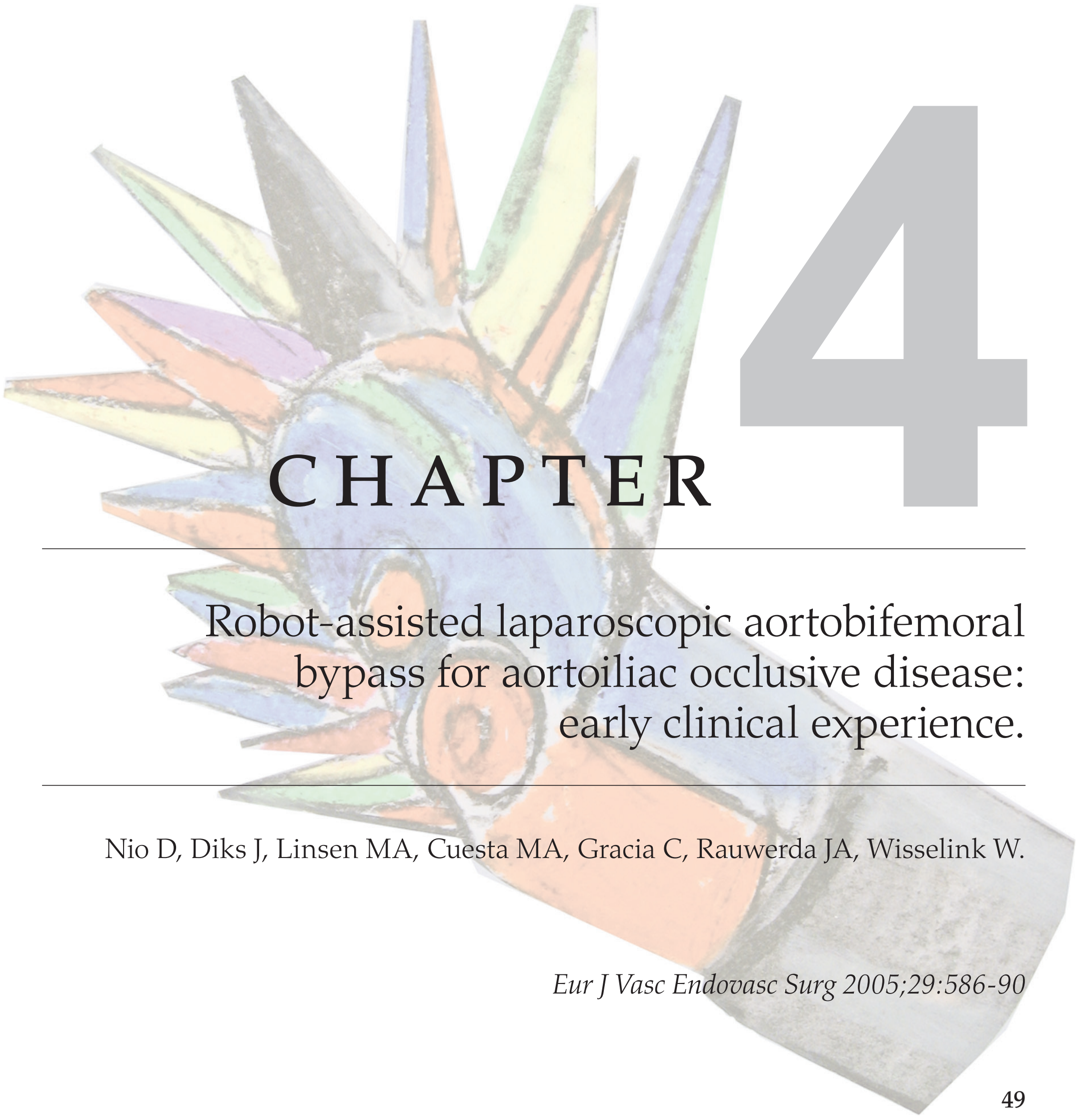

CHAPTER 4

Robot-assisted laparoscopic aortobifemoral bypass for aortoiliac occlusive disease: early clinical experience.

Nio D, Diks J, Linsen MA, Cuesta MA, Gracia C, Rauwerda JA, Wisselink W.

Eur J Vasc Endovasc Surg 2005;29:586-90

Abstract

Background: robotic technology may facilitate laparoscopic aortic reconstruction. We present our early clinical experience with laparoscopic aortobifemoral bypass, aided by two different robotic surgical systems.

Methods: between February 2002 and April 2004, we performed eight robot-assisted laparoscopic aorto-bifemoral bypassesfor aortoiliac occlusive disease. All patients were male; median age was 55 years (range: 36–64). Dissection was performedlaparoscopically and the robotic system was used to construct the aortic anastomosis.

Results: a robot-assisted anastomosis was successfully performed in seven patients. Median operative time was 405 min(range: 260–589), with a median clamp-time of 111 min (range: 85–205). Median blood loss was 900 ml (range: 200–5800).Median anastomosis time was 74 min (range 40–110). In two patients conversion was necessary, one due to bleeding of anearlier clipped lumbar artery after completion of the anastomosis, the other because of difficulties with the laparoscopicexposure of the aorta. On post-operative day 3 one patient died unexpectedly as a result of a massive myocardial infarction.Median hospital stay was 7.5 days (range: 3–57).

Conclusion: our initial experience with robotic assisted laparoscopic surgery (RALS) shows it is a feasible technique foraortoiliac bypass surgery. However, laparoscopic aortoiliac surgery demands considerable experience and operative times need to be reduced before this technique can be widely implemented.

Introduction

Laparoscopic vascular surgery for aortoiliac disease has evolved from hand-assisted laparoscopic to totallaparoscopic procedures [1 - 8]. Although impressive series of totally laparoscopic procedures have beenreported, it is still not widely accepted and considered a demanding procedure [6 - 8]. Laparoscopic dissectionand exposure of the aorta can be complicated by loss of visualization due to leakage of carbon dioxide or the intrusion of bowel into the operative field. In addition, making a totally laparoscopic vascular anastomosis requires experience and technical skill. Robotic systems have been shown to facilitate advanced lapa-ros-copic techniques, such as suturing, knot-tying and performance of vascular anastomosis [9]. We report our early experience with two different robotic systems for totally laparoscopic aorto-bifemoral bypass.

Methods

In a period of 26 months (between February 2002 and April 2004) eight patients underwent robot-assisted aorta-bifemoral bypasses after informed

consent. The number of patients is low due to the limited availability of the robotic systems and reducing indication for this procedure. In the reported study period, a robotic system was not available for several months. The first (Zeus-Aesop) system was on a limited loan and only recently our hospital acquired a da Vinci system. During the whole period we performed 18 procedures for occlusive aortoiliac disease: eight robot-assisted aortobifemoral bypasses, two conventional open aortobifemoral bypasses (severe ischemic rest pain, could not be postponed), two endarteriectomies (limited disease), four revascularization procedures for aortoiliac and renal or visceral occlusive disease, one acute type B dissection with mesenteric, renal and lower extremity ischemia and one aortobifemoral bypass as replacement of an infected prosthesis.
All patients were conventionally operated on via a transperitoneal route. Because our experience with manually laparoscopic vascular anastomoses was insufficient, the infrarenal aortobifemoral bypasses in patients with severe ischemic rest pain were conventionally operated in the period of absence of a robotic system. Suprarenal, mesenteric revascularization and redo surgery were not deemed suitable for laparoscopic surgery with our current experience. The first five patients were operated with a Zeus-Aesop surgical robotic system® (Computer Motion, California, USA) and the latter three patients were operated with a da Vinci surgical system® (Intuitive Surgical Inc, California, USA).

Surgical Technique

All operations were performed by the same surgical team (vascular surgeon (WW) and laparoscopic surgeon (MAC)), whereas the first two procedures were accompanied by a vascular surgeon with extensive robotic experience (CG) [10]. A system engineer was present to assist all procedures.

Median age was 55 years (range 36–64). Operative indications were intermittent claudication (n=7) or ischemic rest pain (n=1). Mean ankle-arm index (AAI) was 0.51±0.20 in rest; 0.30±0.15 following exercise. Pre-operative work-up consisted of an arteriogram (n=7) or MRA (n=1). Five patients had unilateral occlusion of the common iliac artery (CIA) in combination with occlusion of the external iliac artery (EIA) with contralateral stenosis in the iliac arteries.
Two patients had occlusion of the CIA with extensive stenotic lesions in the ipsilateral EIA and stenotic lesions in the distal aorta and contralateral iliac arteries. One patient had a distal aortic occlusion in combination with occlusion of the iliac arteries on both sides. Because of the length and severity of the occlusive and stenotic lesions surgical treatment was preferred to endovascular revascularization.

All operations were performed under general anesthesia and dissection of the aorta was performed laparoscopically, subsequently the robotic system was introduced and the aortic anastomosis was performed. Patient positioning varied with robotic system. The robotic arms of the Zeus® are connected to the operating table rails and the patients were placed in a supine position with the left flank slightly tilted as described earlier [10].The arms of the da Vinci® are mounted on a mobile surgical cart, which is positioned next to the operating table. Patients were placed in a right lateral decubitus position with rotation of the pelvis for access to the femoral arteries. The da Vinci® unit was placed at the right (ventral) side of the patient, with the robotic arms positioned over the patient (Fig. 1).

In the first two patients conventional laparoscopic dissection of the aorta was performed using the apron technique with suspension of the apron to the anterior abdominal wall as described by Dion et al [11]. These patients have been described in a case report earlier [10]. In the remaining six patients retroperitoneal dissection was performed with a dissection balloon (Origin Medsystems Inc., Menlo Park, California, USA) under intraperitoneal laparoscopic visual control to establish the creation of a pneumoretroperitoneum [12]. Femoral arteries were dissected manually by standard groin incisions.

All patients were given systemic heparin before clamping of the aorta. A polytetrafluororethylene (PTFE) (WL Gore and Associates, Flagstaff, Arizona, USA) prosthesis was stained orange with rifampicine to prevent light

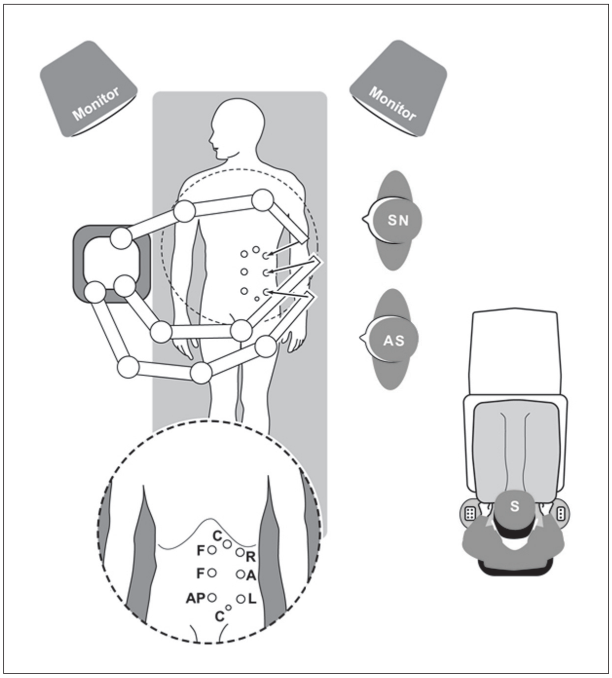

Fig 1: Set-up of da Vinci with trocar positioning. Operating room set-up. RC, robotic cart; C, surgeon control console; AS, assistant surgeon; SN, scrub nurse; Inset: R, right robotic arm; L, left robotic arm; A, surgical endoscope positioner. Trocar positions in abdominal wall: C, Aortic clamp; F, fan retractor

reflections. A PTFE graft was used because of the relative stiffness of this material. This enabled us to bend the edges of the prosthesis to facilitate eversion of the anastomosis. CV-4 PTFE (WL Gore and Associates, Flagstaff, Arizona, USA) sutures were used. Extra-corporally two sutures were cut to the appropriate length and tied, thereby creating a custom made double-armored suture. A U-stitch was placed in the heel of the prosthesis, where after the prosthesis with sutures in place was introduced through one of the trocars and an end-to-side anastomosis was made with a running suture technique. A zero degree endoscope was used for the dissection and a 30-degree endoscope for the vascular anastomosis. Six 10 mm trocars were introduced in the right hemiabdomen to allow dissection and provide visibility of the aorta (Fig. 1).

Results

In all patients, the aortobifemoral bypass was successfully implanted; however, additional abdominal incisions were necessary in two patients. In one case (#6), after making the robot-assisted aortic anastomosis, bleeding from an earlier clipped lumbar artery resulted in a loss of visibility that coincided with severe declamping hypotension. An acute conversion was made by means of a 15 cm flank incision to control the bleeding. The robotic vascular anastomosis showed no leakage. The patient, however, required prolonged post-operative respiratory support and developed transient renal failure and severe critical illness polyneuropathy. At follow-up after 6 months he had made a near complete recovery.

The second conversion (case #8) was caused by tearing of the peritoneum, which resulted in continuous CO2 leakage and bowel migrating into the retroperitoneal space, thereby obstructing the operative field and vision. A 15 cm flank incision was made for retraction and performance of a hand sewn end-to-side anastomosis. On the 3rd post-operative day one patient died unexpectedly due to a massive myocardial infarction. At autopsy, pin-point stenoses of the left anterior descending coronary artery was found, that unfortunately had been missed during the pre-operative cardiac work-up. All aortic anastomoses were dry and patent following removal of the aortic clamps.

Some technical problems with the robotic system (Zeus®) were encountered. Several times the instruments malfunctioned and once the voice-controlled Aesop® camera system did not respond, resulting in significant operative delay. A suture break occurred once (case #7), during performance of the robotic anastomosis, requiring the use of an additional suture.

Median operative time was 405 min (range: 260–589), with a median clamp-time of 111 min (range: 85–205). Median anastomosis time was 74 min (range: 40–110). Median blood loss was 900 ml (range: 200–5800). Median hospital stay was 7.5 days (range: 3–57). (Table 1). Median follow-up was 12 months (range: 3–30). Five patients remained free of intermittent claudication, one had a pain free walking distance of 300 m due to pre-existent infrainguinal occlusive disease, and one patient had a limited walking distance due to dyspnoea of cardiac origin. AAI's were normal (>1.0) in all but one patient (0.7). Duplex examination at 6 months intervals revealed all anastomosis to be patent without stenoses or false aneurysms.

Table 1. Results

	Operating time *(min)*	Anastomosis time *(min)*	Clamp -time *(min)*	Blood loss *(ml)*	ICU stay *(days)*	Hospital stay *(days)*	Conver-sion	Follow-up (months)
1	290	74	104	200	1	4	No	30
2	260	60	90	200	1	6	No	30
3	380	65	125	700	1	8	No	16
4	420	85	175	1000	1	4	No	12
5	455	110	205	800	3	3	No	-
6	589	40	105	5800	16	57	Yes	6
7	390	60	117	1650	1	6	No	3
8	495	-	85	3000	1	10	Yes	3

Discussion

Laparoscopic surgery has developed rapidly since, its introduction. Even though operative times are longer the benefit of laparoscopic surgery (less pain and post-operative complications, reduced hospital stay, earlier return to work and better cosmetic appearance) are well recognized and laparoscopic surgery has become the standard for several procedures [13].The enthusiasm for laparoscopic aortoiliac surgery is, however, low. Despite early positive reports it has not been widely embraced [5 - 8 and 14] .Two major problems are encountered: the maintenance of a stable operative field with clear vision and the performance of the vascular anastomosis.

For the laparoscopic dissection of the aorta three different techniques are used: a transperitoneal route, a retroperitoneal route and an apron technique [11, 14 and 15]. With the transperitoneal approach, intrusion of bowel in the operative field is prevented by (extreme) patient positioning, in the latter two approaches, the peritoneum is used towards this goal. The first patients were operated on with the use of an apron peritoneal layer, which provided a stable operative field. However, it also proved to be a tedious and time consuming technique. The retroperitoneal approach with a dissection balloon can be performed quickly, but results in a relatively small retroperitoneal space which easily collapses with suction or CO_2 leakage. The retroperitoneal flap is thin and even a small hole in this layer results in CO_2 leakage or intrusion of bowel, with collapse of the working space or loss of visibility. For the transperitoneal route [15] the patient has to be extremely rotated, which interferes with the positioning of the da Vinci robotic arms.

Vascular anastomoses can be performed totally laparoscopically, which requires advanced laparoscopic skill and regular practice to maintain these skills. Robotic surgery facilitates laparoscopic suturing and knot-tying by robotic instruments with additional degrees of freedom and 3D-vision, bypassing intensive practice. An additional advantage of a robotic system is the minimal dissection of the aorta and iliac vessels required. Robotic systems were used for the vascular anastomosis only. Both robotic systems have distinct advantages. The table mounted arms of the Zeus® are not obstructive and leave many options for patient positioning. The da Vinci® system on the other hand, is bulky and dominates the surgical field. Concerning technical performance of the robotic instruments, the da Vinci® offers more degrees of freedom and manipulation of its instruments is more intuitive.

When compared to total laparoscopic procedures, [5 - 7] reported operating times are longer (375, 227 and 290 vs. 405 min) especially considering the fact that in the series reported by Kolvenbach [6] and Coggia [7] two laparoscopic aortic anastomoses were made. However, both authors have a great amount of clinical experience with laparoscopic (assisted) vascular surgery and are supposed to have passed their learning curve. When compared to the earliest totally laparoscopic series for aortobifemoral bypasses by Dion [5] clamping time and anastomosis time are similar (121 and 66 min vs. 111 and 74 min). In the reported robot-assisted cases by Kolvenbach, [6] operating time and aortic cross clamping times were longer, but robot-assisted aortic anastomosis time was significantly shorter (52.7 vs. 40.8 min). The set-up time and mechanical problems with their robotic system was associated with longer operating time despite shorter anastomosis time. An improved robotic system might also shorten operating times.
Difficulty performing aortic dissection is the main factor prolonging the operative time for this procedure. Another report by Desgranges [16] describing robot-assisted procedures also reports prolonged dissection time. Operating time was short (188 min) but in 3/5 patients a minilaparotomy was performed for

exposure of the aorta. Aortic anastomotic time was not reported, but mean cross clamping time was 75 min. The robotic instruments have more degrees of freedom of movement and facilitate actions that cannot be made by conventional instruments and improve efficacy by reduction of actions to make endoscopic stitches and knots, however, at present the anastomotic time is prolonged [9].

A robotic system is an expensive laparoscopic adjunctive instrument. Although, a cost analysis was not performed in our study, but robotic-assisted surgery can be assumed to be more expensive than open and conventional laparoscopic surgery. This should be taken in consideration before starting RALS. Robotic systems are still developing and improving. Technical improvements will reduce the complexity of robotic systems and probably shorten the learning curve for the vascular surgeon. In conclusion, RALS for aortoiliac surgery can be of additional value in overcoming the long learning curve in laparoscopic suturing of vascular anastomoses. However, in this study the laparoscopic exposure of the infrarenal aorta was time consuming and not always predictable. Therefore, this procedure requires continued research before wide implementation can be expected.

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CHAPTER 5

Robot-assisted laparoscopic surgery of the infrarenal aorta: the early learning curve.

Diks J, Nio D, Jongkind V, Cuesta MA, Rauwerda JA, Wisselink W.

Surg Endosc 2007;21:1760-3
Erratum in: Surg Endosc 2007;21:2118-9

Abstract

Background: Recently introduced robot assisted laparoscopic surgery (RALS) facilitates endoscopic surgical manipulation and thereby reduces the learning curve for (advanced) laparoscopic surgery. We present our learning curve with RALS for aortobifemoral bypass grafting as a treatment for aortoiliac occlusive disease.

Methods: Between February 2002 and May 2005, 17 patients were treated in our institution with robot-assisted laparoscopic aorto-bifemoral bypasses. Dissection was performed laparoscopically and the robot was used to make the aortic anastomosis. Operative-, clamping- and anastomosis times, blood loss and hospital stay were used as parameters to evaluate the results and to compare the first eight (group 1) and the last nine patients (group 2).

Results: Total median operative -, clamping - and anastomosis times were 365 minutes (range: 225 - 589), 86 minutes (range:25 - 205) and 41 minutes (range: 22 - 110) respectively. Total median blood loss was 1000 ml (range: 100 - 5800). Median hospital stay was 4 days (range 3 - 57). 16/18 anastomoses were completed with the use of the robotic system. Three patients were converted (two in group 1, one in group 2) and one patient died postoperatively (group 1). Median clamping and anastomosis times were significantly different between group 1 and 2 (111 minutes (range 85 – 205) vs 57.5 minutes (range 25 – 130), $p < 0.01$ and 74 minutes (range 40 – 110) vs 36 minutes (range 22 – 69), $p < 0.01$ respectively) Total operative time, blood loss and hospital stay showed no significant difference between group 1 and 2.

Conclusions: Robot-assisted aortic anastomosis showed to have a steep learning curve with considerable reduction of clamping and anastomosis times. However, due to a longer learning curve for laparoscopic dissection of the abdominal aorta, operation times were not yet significantly shortened. Even with robotic assistance, laparoscopic aorto-iliac surgery remains a complex procedure.

Introduction

Over the last decade, laparoscopic techniques in vascular surgery have evolved from laparoscopy assisted and hand-assisted laparoscopy, to total laparoscopic procedures. A small group of pioneers have shown it to be a feasible technique for both the treatment of aortoiliac occlusive disease as for aneurysm repair [1 - 5]. However, vascular surgeons seem reluctant to introduce it into their every day practice. This can be explained by the technical difficulties of this approach. Laparoscopic dissection of the abdominal aorta is a difficult procedure; due to collapse of the operating field or migrating bowels it can be difficult to maintain a clear view. Secondly, creation of the aortic anastomosis is challenging, demanding a great deal of practice and technical skill. These may contribute to a long learning curve in laparoscopic vascular procedures. Recently introduced robotic surgical systems are known to facilitate technically challenging laparoscopic techniques, such as suturing, knot-tying and creation of intracorporeal anastomoses [6]. Introducing these robotic systems to aid in laparoscopic vascular procedures may help overcome long learning curves and the necessity to maintain ones laparoscopic skills on a more than regular basis.

Methods

After an initial series of 8 robot-assisted laparoscopic aortobifemoral bypasses for aortoiliac occlusive disease [7], we expanded our series to a total of 17 patients between April 2004 and May 2005. The latter patients were all operated with use of a da Vinci surgical system (Intuitive Surgical inc., Sunnyvale, CA, USA). During this period (April 2004 - May 2005), we operated a total of 21 consecutive patients for aortoiliac occlusive disease: 9 robot assisted laparoscopic aortobifemoral bypasses, endarteriectomies (limited disease) and 9 conventional aortobifemoral bypasses via a transperitoneal route. Reasons for conventional operations were; replacement of infected prostheses (n = 4), abdominal adhesions in patients with previous abdominal surgery (n = 2), redo-surgery of an occluded prosthesis (n = 1) and extensive renal and visceral occlusive disease, necessitating suprarenal clamping (n = 1). In these cases (n= 8), robot assisted laparoscopic surgery (RALS) was not deemed suitable because of our limited experience. One patient needed emergency surgery for acute ischemia when the robot was not available. All procedures were conducted by the same team of surgeons (an experienced vascular surgeon (WW) and an experienced laparoscopic surgeon (MAC)), while the same team of (scrub-)nurses attended all the operations. Surgical assistants rotated and an engineer from Intuitive Surgical was present to assist in all operations.

16 men and 1 woman, median age 55 years (range 36 – 72), were operated for aortoiliac occlusive disease with disabling intermittent claudication. Pre-operative imaging consisted of arteriogram (n = 16) or MRA (n = 1). All patients had underwent previous attempts to revascularization with either PTA (n = 4), stent placement (n = 6) or both (n = 7) and had preoperatively been diagnosed with either TASC (TransAtlantic Inter-society Consensus) type C or - D lesions (see table 2). Median body mass index (BMI) was 25.4 (range 19.8 – 36.8) and median ankle-arm index (AAI) was 0.70 (range 0.90 – 0.35) in rest and 0.35 (range 0.13 – 0.52) after exercise. Pre-operative clinical condition was described using the American Society of Anesthesiologists classification (ASA-classification, see table 2). All data was obtained prospectively.

Surgical technique:
Details of different surgical techniques have been described elsewhere [1 - 5, 8, 9]. We initially used a transabdominal approach with the ‘apron’ technique, as described by Dion et al. [8]. In this approach, a peritoneal ‘flap’ is dissected laparoscopically and subsequently used to ‘suspend’ the intestines onto the abdominal wall from inside the abdominal cavity with stitches, in order to keep a clear operative field. We also have used a retroperitoneal approach [9], in which a retroperitoneal space is created by digital dissection, followed by use of a dissection balloon. However, we encountered problems with both these techniques, i.e. ‘tearing’ of the peritoneal flap in the ‘apron’ approach (which lead to loss of visibility) and loss of visibility after suction in the retroperitoneal approach. Finally, we preferred the transabdominal approach with extreme patient-rotation as described by Coggia et al. [5]. In short: under general anesthesia, the patient is positioned supine with a Pelvic Tilt pillow (O.R. Comfort, LLC, Branchburg, NJ, USA) under the left flank. Via small groin incisions, the common femoral arteries are exposed on both sides. Subsequently, the operating table is maximally rotated and the pillow is inflated, until a right lateral and rotated decubitus position is achieved with the abdomen rotated at 85-90°.

The surgeon is standing at the right side of the patient, facing the patient’s abdomen and the video monitor, which is placed at the patients left side. After a pneumoperitoneum (14 mmHg) is achieved, six 12 mm trocars are inserted (figure 1). One trocar is placed at the left anterior axillary line, 3 centimeters below the costal margin, to insert a 30° endoscope (STORZ Endoskop Produktions GmbH, Tuttlingen, Germany). Subsequently, additional trocars are placed under direct videoscopic vision 7 centimeters supraumbillically and 11 centimeters below the costal margin, just lateral to the left anterior axillary line. These will be used by the surgeon during dissection and by the robotic instruments during the anastomosis. A trocar for retraction of the bowel is placed left paraumbilically and assistant ports are placed 6 centimeters under the navel and in the left lower abdomen at mid-clavicular level.
Dissection of the left colon is performed and a fan retractor is placed into an Endoscope Holding system (KARL STORZ GmbH & Co. KG, Tuttlingen, Germany) to keep the bowel from migrating into the operative field. Clipping of the lumbar arteries is performed with a Ligasure™ Vessel Sealing System (Valleylab, Boulder, CO, USA) and the inferior mesenteric artery is temporarily occluded.
Two retroperitoneal tunnels are prepared from the groin incision towards the aorta by means of passing a blunt clamp, visualizing intra abdominal passage with the endoscope.

Aortic clamps are placed in position; the proximal clamp is inserted through an incision in the abdominal wall, just below the xyphoid, and the distal clamp is inserted through an earlier placed trocar (figure 1). Subsequently the robotic system, which is previously covered in sterile drapes, is introduced into the surgical field. The surgeon takes place behind a remote console, from which the robotic arms are controlled. The endoscope is replaced by a 30° 3D-endoscope of the surgical system.

Under systemic heparinization, the aorta is clamped just distal to the renal arteries and below the inferior mesenteric artery. An aortotomy is made with a pair of pots scissors (Endowrist™ Pots Sisscors, Intuitive Surgical, Sunnyvale, CA, USA). A bifurcated polytetrafluororethylene (PTFE) (WL Gore and Associates, Flagstaff, Arizona, USA) prosthesis is stained orange with rifampicine to prevent light reflections. An end-to-side anastomosis is made with a CV-4 PTFE (WL Gore and Associates, Flagstaff, Arizona, USA) running suture with two robotic needle drivers (Endowrist® Needle Drivers). Following completion of the aortic anastomosis the two graft limbs are tunnelled to the groins where a conventional end-to-side anastomosis is performed to the common femoral artery.

Statistical analysis:
Statistical analysis was performed using a Mann Whitney U test in SPSS 12.0 for Windowstm to compare operative parameters between our earlier 8 patients (group 1) and our most recent 9 patients (group 2). A p-value of $p < 0.05$ was considered statistically significant.

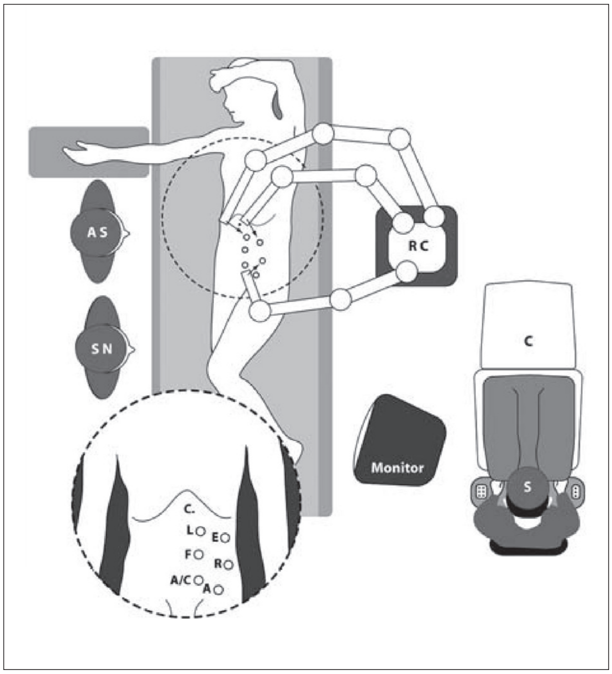

Fig 1: Setup in OR and trocar positions: RC: tobotic cart; C: robot-console; S: surgeon; AS: assistant; SN: scrub nurse. Inset: C: aortic clamps; F: fan retractor; E: surgical endoscope; R: right robotic arm; L: left robotic arm; A: assistants' ports.

Results

In all patients, an aortobifemoral bypass graft was successfully inserted. However, conversion to open surgery was necessary in three patients, of which two cases (patient # 6 and #8) have been described previously [7]. A third conversion (patient # 9) was required due to a technical problem with the robotic system; the battery was not recharged and it was considered unsafe to proceed without a backup energy source. One patient (# 11) had to be readmitted into surgery on postoperative day one, due to leakage from the prosthesis. A laparotomy was performed and a hematoma was encountered in the retroperitoneal space. The prosthesis showed a small puncture hole, probably due to robotic manipulation. One patient (# 3) died unexpectedly on postoperative day 3 due to a massive cardiac infarction [7].

Total median operative time was 365 minutes (range 225 - 589), with a median clamp-time of 86 minutes (range 25 - 205) and a median anastomosis time of 41 minutes (range 22 – 110). Median blood loss was 1000 ml (range: 100 - 5800). Median hospital stay was 4 days (range:3 - 57) and we have a median follow-up of 18 months (range 6 – 48).

When group 1 is compared to group 2, a significant difference is seen in clamp time (median 111 minutes (range 85 – 205) vs median 57.5 minutes (range 25 – 130), $p < 0.01$) and in anastomosis time (median 74 minutes (range 40 – 110) vs median 36 minutes (range 22 – 69), $p < 0.01$). No significant difference was seen in median operative time (405 minutes (range 260 - 589) vs 339 minutes (range 225 - 465)), median blood loss (900 milliliters (range 200 - 5800) vs 950 milliliters (range 100 - 1800)) and hospital stay (7.5 days (range 3 - 57) vs 4 days (range 4 - 15)) (tab. 1). During follow-up, all patients had a Duplex examination at 6 months to verify patency of the prosthesis. No stenoses or false aneurysms were encountered. AAI's were normal (> 1.0) in all but one patient (0.7 in rest, due to preexistent femoral occlusive disease). All patients remained free of intermittend claudication.

Tables

	Operative time *(minutes)*	Clamp time *(minutes)*	Anastomosis *time (minutes)*	Blood loss *(milliliters)*	Hospital stay *(days)*
First 8	405 (260 – 589)	111 (85 – 205)	74 (40 – 110)	900 (200 - 5800)	7.5 (3 – 57)
Latter 9	339 (225 – 465)	57.5 (25 – 130)	36 (22 – 69)	950 (100 – 1800)	4 (4 – 15)
p - value	p = NS	p < 0.01	p < 0.01	p = NS	p = NS

table 1: median parameters (range) and statistical significance.

	ASA	TASC	OR time *(min.)*	Blood loss *(milliliters)*	Clamp -time *(min.)*	Anastomosis time *(min.)*	ICU stay *(days)*	Hospital stay *(days)*	Convervion	Follow -up *(months)*
1	II	D	290	200	104	74	1	4	No	48
2	III	D	260	200	90	60	1	6	No	48
3	II	D	380	700	125	65	1	8	No	36
4	II	D	420	1000	175	85	1	4	No	36
5	III	D	455	800	205	110	3	3	No	36
6	III	C	589	5800	105	40	16	57	Yes	24
7	II	D	390	1650	117	60	1	6	No	24
8	II	C	495	3000	85	X	1	10	Yes	24
9	III	C	335	1000	25	X	1	11	Yes	18
10	II	C	260	1150	70	30	1	4	No	12
11	II	D	465	900	130	40	3	15	No	12
12	II	D	355	1100	55	25	1	4	No	12
13	II	D	388	600	60	69	1	4	No	12
14	II	D	343	1350	55	39	1	4	No	12
15	III	C	310	600	60	36	1	4	No	6
16	II	C	225	100	35	22	1	4	No	6
17	II	C	365	1800	86	41	1	4	No	6

table 2: parameters per patient

Discussion

Since the introduction of minimal invasive vascular surgery, techniques such as laparoscopy assisted and hand assisted laparoscopic procedures for aortobifemoral bypass grafting have been developed [10, 11], in which the aortic dissection is performed laparoscopically in contrast to the conventional 'open' method, which requires a long abdominal incision. Laparoscopic creation of an aortic anastomosis however, is indisputably challenging and requires a great deal of practice and experience before being applied into every day clinical practice [12, 13]. The addition of robotic assistance to these procedures offers an ergonomic and natural interface between the surgeon's hands and the instrument tips, as well as increased freedom of motion due to wrist action of the robotic instruments. It therefore seems to facilitate creation of the aortic anastomosis, making a total laparoscopic procedure for aortobifemoral bypass grafting easier accessible to the 'common' vascular surgeon.

Laparoscopic dissection of the abdominal aorta can be performed via a retroperitoneal route and a transabdominal route. The retroperitoneal route [9] is an easy and fast technique, The obtained space however, is small and tends to collapse when suction is used. In case of bleeding, conversion to open surgery is nearly unavoidable.

The 'apron' technique [8] is a time consuming technique and the thin apron flap is tears easily,which often results in conversion. After initial experience with both these techniques, we chose for the transabdominal route [5], using extreme patient rotation. This technique offers a clear and stable operative field, using a fan retractor to keep bowels from migrating into the operative field.

With the addition of robotic technology to conventional laparoscopic surgery, we have shown to shorten the learning curve considerably with regard to creation of the aortic anastomosis. Compared to various larger series [12 -17], the aortic anastomosis time and the aortic clamp time are acceptable after the first 8 patients. In our institution patients are treated by matter of endovascular techniques for aortoiliac occlusieve diease and only few patients need surgery. Even without a daily or weekly routine, we still showed to improve our anastomosis-times. This suggests that robotic manipulation does not require as much practice and maintenance of skills as does conventional laparoscopy.

However, the greater part of this procedure consists of the laparoscopic dissection of the abdominal aorta. Due to our search toward the 'best' approach and to the technical challenge of this advanced laparoscopic procedure (e.g. control of bleeding [18]), we have yet to complete our learning curve for the laparoscopic part of this procedure before a considerable drop in operative time can be anticipated.

RALS is an expensive method, due to the robotic system, its instruments and maintenance of the system. Although a cost analysis was not conducted in our study, it can be assumed to be more expensive then conventional technologies and these remarks should be considered before applying RALS into any institution. With new technological developments on the horizon, robotic systems may rapidly become less expensive, less bulky and more manageable in the near future, making it accessible for a greater audience.
In conclusion, after 8 cases we have endured a learning curve for the robotic part of RALS for aortobifemoral bypass grafting. The most critical part of the operation, the aortic clamp time, has been more than halved. But even with robotic facilitation of the aortic anastomosis, long operative times are still anticipated due to the learning curve of laparoscopic aortic dissection.

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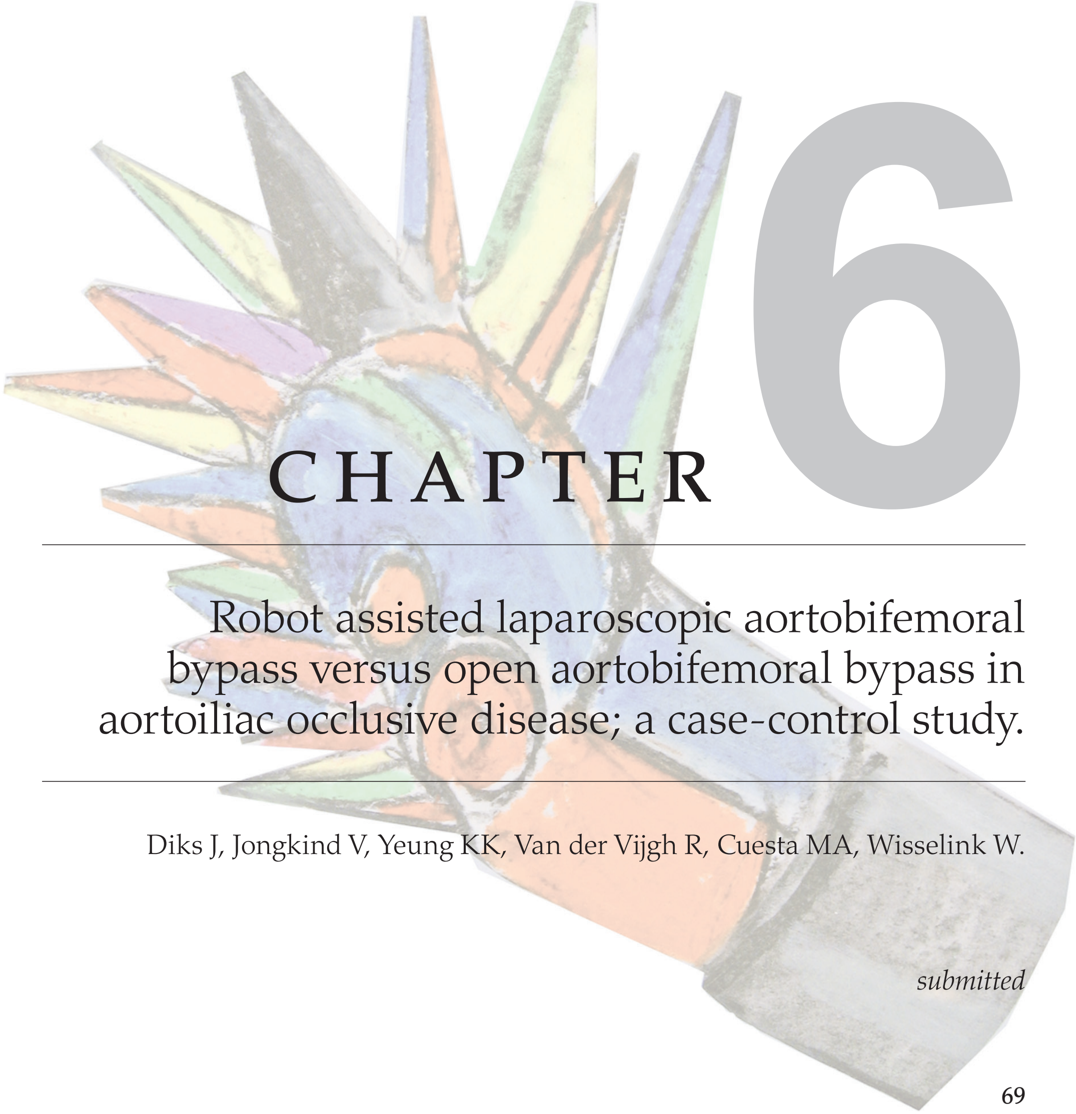

CHAPTER 6

Robot assisted laparoscopic aortobifemoral bypass versus open aortobifemoral bypass in aortoiliac occlusive disease; a case-control study.

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submitted

Abstract:

Background: In a number of non-comparative reports, robot assisted laparoscopic aortobifemoral bypass has been deemed as a safe and feasible alternative surgical technique for treatment of patients with aortoiliac occlusive disease. We conducted a case control study to compare robot assisted laparoscopic repair to the gold standard, the conventional open approach.

Methods: Between 2002 and 2007, 24 patients have undergone robot assisted laparoscopic aortobifemoral bypass in our institution. This group was compared to a consecutive series (n=30) treated with open surgical technique in the period just before our implementation of the robot assisted technique.

Results: Both patient groups were similar as ischaemic symptoms, body mass index, cardio vascular risk factors, co-morbidity and extent of aortic disease. Operative times and aortic clamping times were significantly shorter in the 'open' group (232.5 vs 360 min, $p < 0.01$ and 50 vs 71.5 min, $p = 0.02$), whereas post-operative data show a significant favor toward the 'robot assisted' group; ICU stay 1 vs 2 days ($p < 0.01$), resumption of normal diet 2 vs 5 days ($p < 0.01$), resumption of ambulation 3 vs 4 days ($p < 0.01$) and total hospital stay 6 vs 14.5 days ($p < 0.01$).

Conclusion: In spite of longer operative and clamping times, robot assisted laparoscopic aortic bypass was associated with a significantly quicker postoperative recovery compared with open surgical repair.

Introduction:

It has been well over a decade since first reports of a minimally invasive approach to the abdominal aorta have been published [1 - 3]. Various developments have since been described; from laparoscopy assisted open surgery [1], to hand assisted laparoscopic surgery (HALS) [4], to a total laparoscopic approach [5, 6]. It has been clear though, that total laparoscopic aortoiliac surgery requires a great deal of dedication and devotion before it can be implemented into everyday practice [7, 8]. Accordingly, to the 'common' vascular surgeon, assistance of a robotic surgical system may be beneficial. This technique has shown to be feasible and has obtained comparable outcomes to total laparoscopic aortoiliac surgery, with a shorter learning curve [9].

Since the first report of this technique [10], several authors have been encouraged to implement this method as a solution to minimally invasive vascular surgery [11 - 14]. Nevertheless, vast acceptance of this strategy seems to hold back.

One important drawback is the fact that patient-selection for aortobifemoral bypass is limited in case of occlusive disease because the extensiveness of percutaneous techniques such as percutaneous transluminal angioplasty (PTA) and endovascular treatments. As for aneurysmal disease, endovascular graft deploy-

ment is making headway rapidly and newer and better stents are being developed, making it a popular choice in the treatment of aortic aneurysms.
Another main hurdles to overcome is acquirement of a robotic surgical system, which nowadays has a cost price of € 1.490.000,= and a € 140.000,= a year service contract. Subsequently, the use of robotic instruments has an average expense of € 200,= for each procedure.

Nevertheless, over 700 robotic systems have been sold worldwide, and robotic surgery has been implemented in many fields of surgery, such as cardiac-, general-, gynecologic-, thoracic-, and urologic surgery [15 - 19]. Many vascular surgeons might have access to a robotic system at their medical center, yet only very few centers report on implementing it in vascular surgery.
The last obstacle may be the lack of scientific evidence. With more evidence, vascular surgeons with a robotic system at their disposal might be motivated to implement this type of minimally invasive surgery into their practice.
We have conducted a case-control study to compare our outcomes in robot assisted laparoscopic surgery to retrospectively obtained outcomes of open aortobifemoral bypasses, performed between 1996 and 2002.

Methods:
Between 2002 and 2007, 24 patients were treated for aortoiliac occlusive disease by means of a robot assisted laparoscopic aortobifemoral bypass (Group A). A detailed description of this procedure has been published earlier. In short, under general anaesthesia, the patient is positioned supine with a Pelvic Tilt pillow (O.R. Comfort, LLC, Branchburg, NJ, USA) under the left flank. After maximum rotation of the operation table and inflation of the pillow, a patient-rotation of 85-90° is achieved.

Using laparoscopic techniques and a 30° endoscope (STORZ Endoskop Produktions GmbH, Tuttlingen, Germany), the left colon is dissected and exposure of the abdominal aorta is obtained. Subsequently, lumbar arteries are clipped using a Ligasure™ Vessel Sealing System (Valleylab, Boulder, CO, USA). The inferior mesenteric artery is temporarily occluded.
After retrograde tunnelling from the groins under direct endoscopic vision, the robotic system is inserted into the operative field. A bifurcated polytetrafluororethylene (PTFE) prosthesis (WL Gore and Associates, Flagstaff, Arizona, USA) (diameter 16 x 8 mm or 14 x 7 mm, depending on the anatomy) is stained orange with rifampicine to prevent light reflections. An end-to-side anastomosis is made with the robotic system using a CV-4 PTFE (WL Gore and Associates, Flagstaff, Arizona, USA) running suture.

After completion of the aortic anastomosis a conventional end-to-side anastomosis is performed to both common femoral arteries. Preoperative, intraoperative and postoperative data were prospectively collected.

A retrospective study was performed to obtain comparative data of 30 open aortobifemoral bypasses (Group B), operated on prior to implementation of the da Vinci robot in our medical center, between 1996 and 2002. Surgical procedure was according to commonly used techniques in basic vascular surgery. Abdominal aortic exposure was obtained through a longitudinal laparotomy and a Dacron graft (Vascutek, Renffewshire, UK) was used.
Preoperative data include gender, age, body mass index (BMI), cardiovascular risk factors, American Society of Anesthesiologists (ASA) class and TransAtlantic Inter-Society Consensus (TASC) score.
Intraoperative data include operative time, aortic clamping time and blood loss. Postoperative data include ICU stay, days to return to normal diet, days to resume ambulation, total hospital stay, complications and mortality.
A statistical analysis of continuous pre-, intra- and postoperative data was made using a Mann–Whitney U test. Categorical data was analyzed using a Chi-square test. A p-value of ≤ 0.05 was considered statistically significant.

Results:
Although a significant higher number of women were operated on in group A (5:19 versus 2:28 ($p < 0.05$)), BMI and cardiovascular risk factors were comparable (table 1). Each group had similar ASA class patients (class 2: 13 versus 14 (NS) and class 3: 11 versus 16 (NS)). Severity of aortoiliac lesions (TASC type) was comparable between both groups (type C: 11 versus 17 (NS) and type D: 13 versus 13 (NS)) (table 1). Total median operative time was 360 minutes (range: 225 – 589) in group A and 232.5 minutes (range: 150 – 360) in group B; a significant difference ($p < 0.001$). Aortic clamping time was significantly shorter in group B; median 50 minutes (range: 15 – 125) versus 71.5 minutes (range: 25 – 205) ($p = 0.002$). No significant difference was found in amount of blood loss; median 1125 milliliters (range: 100 – 5800) in group A versus 1150 milliliters (range: 500 – 2500) in group B (table 2). ICU stay was significantly shorter in group A (1 day (range: 1 – 16) versus 2 days (range: 1 – 6) ($p < 0.001$)). Group A had a earlier resumption of normal diet (postoperative day 2 (range: 2 – 32) versus postoperative day 5 (range: 3 – 24) ($p < 0.001$)). Ambulation was resumed earlier in group A (postoperative day 3 (range: 1 – 43) versus postoperative day 4 (range: 2 – 8). Total hospital stay was 6 days (range: 3 – 57) in group A versus 14.5 days (range 8 – 88) in group B; a significant difference with $p < 0.001$ (table 3).

In group A, conversion to open surgery was necessary in four patients, three of whom (patients 6, 8 and 9) have been previously described [9]. Patient 18 had had previous abdominal surgery and conversion was necessary because no progression could be made during laparoscopic dissection due to abdominal adhesions. One patient (patient 11) had to undergo reoperation on postoperative day one, due to leakage from the prosthesis. A small puncture hole was found and had probably occurred during manipulation with the robotic system.

One patient (patient 3) died on postoperative day 3 after an uneventful operation due to a massive myocardial infarction, probably because his severe cardiac condition was unnoticed during workup.

In group B, one patient (patient 3) had to undergo reoperation on postoperative day one due to occlusion of the crural vessels; an infragenual thromboembolectomy was performed. Two patients had prolonged hospital stay because of persistent gastric paralysis (patient 6: 45 days; patient 8: 21 days). Minor complications in this group occurred in 6 patients (wound infection, cardial asthma, hyperaemia due to reperfusion, maelena due to temporary colic ischaemia). No deaths occurred in group B.

tables:

table 1: Pre-operative data

	Group A	Group B	p-value
Male / Female	19 / 5	28 / 2	< 0.05
Median BMI (range)	26.4 (19.8 – 36.8)	25.9 (18.4 – 35.3)	NS
Median age (range)	57.5 (36 – 72)	63 (40 – 75)	NS
tabacco use (%)	83.3 %	86.6 %	NS
hyperlipidemia (%)	54.2 %	50 %	NS
diabetic (%)	16.6 %	16.6 %	NS
hypertension (%)	70.9 %	76.6 %	NS
ASA class 2	13	14	NS
ASA class 3	11	16	NS
TASC type C	11	17	NS
TASC type D	13	13	NS

table 2: Intra-operative data

	Group A median (range)	Group B median (range)	p-value
Operative time (minutes)	360 (225 – 589)	232.5 (150 – 360)	< 0.001
Aortic clamping time (minutes)	71.5 (25 – 205)	50 (15 – 125)	0.002
Blood loss (millimeters)	1125 (100 – 5800)	1150 (500 – 2500)	NS

table 3: Post-operative data			
	Group A	Group B	p-value
ICU stay (days)	1 (1 – 16)	2 (1 – 6)	< 0.001
Resumption of normal diet (postop day)	2 (2 – 32)	5 (3 – 24)	< 0.001
Resumption of ambulation (postop day)	3 (1 – 43)	4 (2 – 8)	< 0.001
Hospital stay (days)	6 (3 – 57)	14.5 (8 – 88)	< 0.001

Discussion:

Over the last decade, laparoscopic surgery has been widely embraced by surgeons around the world. Aortic surgery however, remains an area in which most procedures are performed by means of a large abdominal incision. As an alternative to this gold standard, endovascular therapy has made great advancement and is widely implemented [20, 21]. However, long-term results still do not surpass those of surgical bypass [22] and its applicability is limited by the extension of occlusive lesion and anatomic suitability. Since (robot assisted) laparoscopic surgery can overcome most of these boundaries, its applicability seems to approach that of open surgery. Furthermore, because a same bypass is performed as in open surgery, its long-term results can be expected to compete with those of conventional aortic surgery.
In our experience with robot assisted laparoscopic aortic surgery, we came across a number of technical difficulties. Most challenging are obtaining a stable operation-field and sewing the aortic anastomosis. Nevertheless, it has been shown that these difficulties can be overcome with a relatively short learning curve when compared to totally laparoscopic aortic surgery [9].

This study was conducted to examine whether the technically more challenging procedure of robot assisted laparoscopic aortic surgery would be beneficial to the post-operative outcomes when compared to conventional aortic surgery. To that extend, a retrospective study was performed to identify a comparable patient-group to our prospectively collected database. All patients were operated on prior to implementation of a robotic surgical system in our institution by the same vascular surgeon (WW). However, a bias in intra- and postoperative events must be considered in this group, due to its retrospective nature.

Operative time was significantly longer in the robot assisted laparoscopy group. Even though the latter group included our initial learning curve, laparoscopic dissection of the abdominal aorta is time-consuming and using the robotic system – preparation and insertion into the operative field – takes extra time. Taking this in consideration, it may be assumed that operative times of a (robot assisted) laparoscopic procedure will never approach those of an open treatment; this drawback has been reported in laparoscopic surgery among several other specialties as well [23 - 25].

An important part of our learning curve is accounted for in the aortic clamping time. It was significantly shorter in the open group, but it was shown earlier that with a short learning curve, aortic clamp time can be halved and a similar clamp time to open surgery can be achieved.

Post-operative data show a favor towards the robot assisted laparoscopic aortic surgery group. Patients had a shorter ICU-stay and shorter postoperative ileus, a complication commonly associated with major abdominal surgery. Resumption of ambulation was significantly sooner when compared to open surgery. This was thought to be associated with less post-operative pain, but no records of pain-scores were found in our retrospective study. Overall hospital stay was over twice as long in the open surgery group.

Shown outcomes suggest robot assisted laparoscopic aortic surgery to be a good alternative for conventional aortic surgery. However, before implementing this technique an extensive training-program is required. The lack of haptic feedback in current robotic systems is a major downside and problems such as rupturing sutures or puncturing a hole in the prosthesis are easily encountered when not proceeding with extreme caution. Furthermore, even with assistance of a robotic system, laparoscopic aortic surgery remains technically demanding and takes a great deal of practice and devotion before it can be implemented into everyday practice.

In our early experience, in spite of longer operative and clamping times, robot assisted laparoscopic aortic bypass was associated with a significantly quicker postoperative recovery compared with open surgical repair. With the ongoing demand for minimally invasive surgical techniques, robotic systems have become available to a growing number of vascular surgeons. However, in spite of promising early reports, more objective data will be required to establish the role of robotic surgical technology in vascular surgery.

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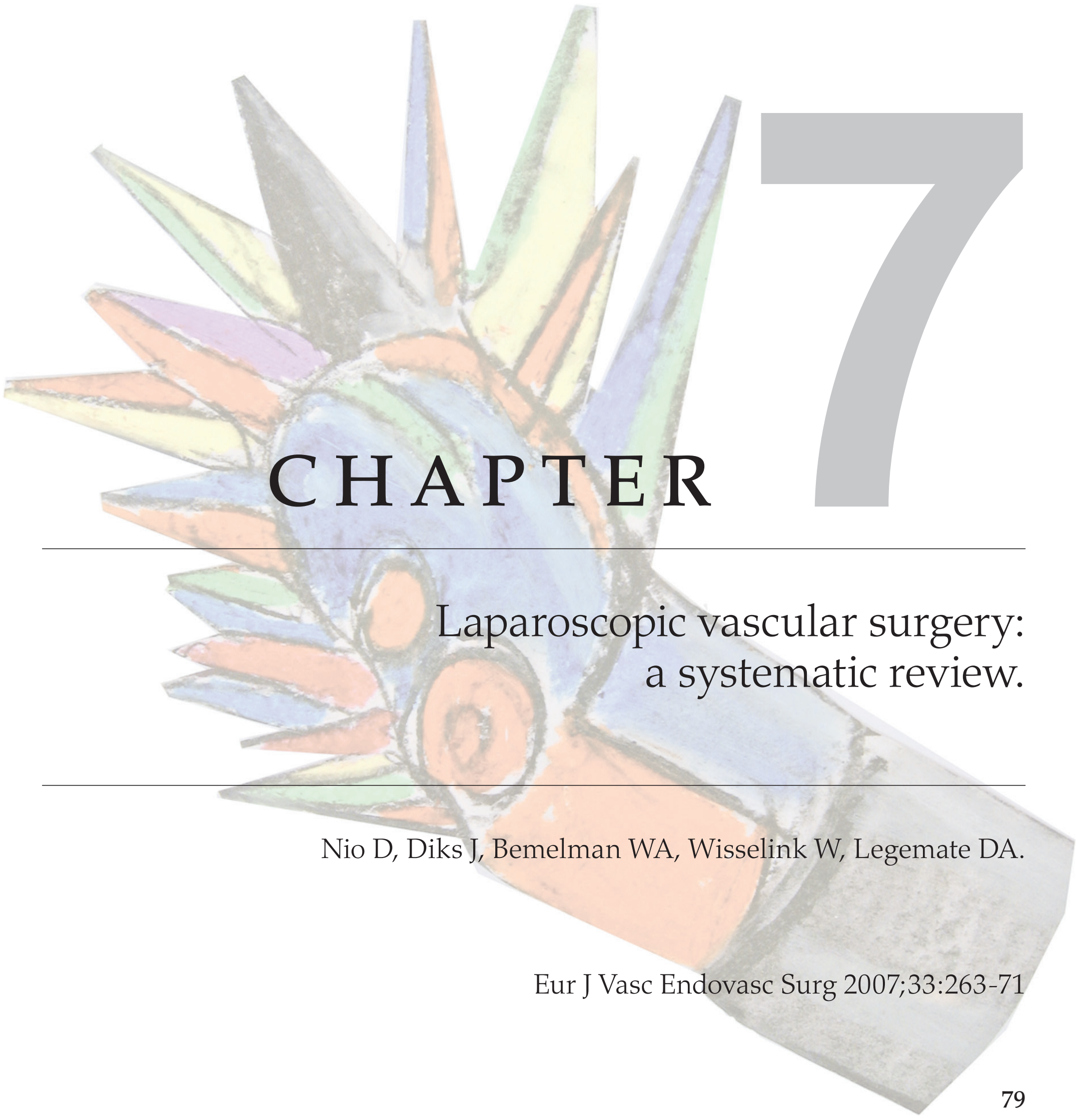

CHAPTER 7

Laparoscopic vascular surgery: a systematic review.

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Abstract

Objective: the objective of this systematic review is to evaluate the results of clinical studies on laparoscopic surgery for aorto-iliac disease.

Methods: a systematic review of the literature from 1966 to September 2006 on laparoscopic and robotic vascular surgery was performed. Only patient series containing more than 5 cases were included. Operative, clamping and anastomosis times, conversion, mortality and morbidity and hospital stay were evaluated.

Results: thirty studies were identified. These were all descriptive and included 9 comparative studies. Operative times varied widely, the shortest being for hand-assisted procedures (2.5–4 hours) and the longest for totally laparoscopic procedures (4–6.5 hours). Clamping times were all < 1 hour in hand-assisted procedures while in other techniques clamping times from 1–2.5 hours were seen. The conversion rate varied from <5% up to 16% in smaller series. The mortality rate was approximately 5% and frequently caused by cardiac ischemia. A variety of problems ranging from minor local wound problems to cardiopulmonary- and renal insufficiency, bleeding, ureter lesions and graft thrombosis were described. Mean hospital stay for nearly all procedures was <1 week.

Conclusion: experience of laparoscopic surgery for aorto-iliac disease is still limited. Most study results are biased by patient selection. Only a few surgeons have mastered the required surgical technique and more data are needed to asses the clinical potential of this type of surgery, in comparison with the endovascular alternative. For wider implementation simplification of the surgical procedure seems necessary.

Introduction

In 1993 Dion[1] took the first step towards laparoscopic vascular surgery by performing a laparoscopy assisted aortobi-femoral bypass. Since then various endoscopic techniques and approaches have been developed to make laparoscopic treatment of occlusive and aneurysmal disease of the aorto-iliac vessels possible. At the same time, the number of endovascular options for treatment of aorto-iliac disease is still growing and the role of laparoscopic vascular surgery should be considered against the background of these ongoing developments.

Laparoscopic techniques include totally laparoscopic (both dissection and anastomosis carried out laparoscopically) as well as laparoscopic-assisted techniques involving hand-assisted laparoscopy (hand-assisted to facilitate the total procedure) and laparoscopic-assisted (laparoscopic dissection combined with a mini-laparotomy to perform a conventional vascular anastomosis). Recently, endoscopic surgery has seen the introduction of surgical robotic systems. In laparoscopic vascular procedures, these systems are mostly used to facilitate laparoscopic suturing of the anastomosis, and sometimes they are applied to the dissection of the aorta. [2 - 6]

The objective of this systematic review is to evaluate the results of clinical studies on laparoscopic and robotic surgery for aorto-iliac disease.

Methods

Literature search

A computer-assisted search was performed in the medical databases Medline (from January 1966 to September 2006), Embase (from January 1988 to September 2006) and the Cochrane Database of Systematic Reviews, using the keywords "laparoscopy AND vascular surgery". With the assistance of a clinical librarian an additional extensive search was performed using a combination of the following Medical Subject Heading (MeSH) terms: Surgery, Laparoscopy, Endoscopy, Vascular Surgical Procedures, Aorta, Abdominal, Renal Artery, Iliac Artery, Gastroepiploic Artery, Epigastric Arteries, Aortic Aneurysm, Abdominal, Iliac Aneurysm, Abdomen, Arteries, Aneurysm, Aortic Diseases, Arterial Occlusive Diseases. After identifying relevant titles, the abstracts of these studies were read to decide if the study was suitable. A manual search of reference lists of studies thus obtained was conducted for any relevant articles not found in the computerized search.

Criteria for inclusion

Clinical studies eligible for inclusion were those which described laparoscopic surgery performed for aorto-iliac disease. Case reports and small series <5 patients were excluded. Articles in languages other than English and German were excluded.

To be eligible articles had to describe original patient series. Studies containing duplicate material were excluded and the larger of the studies, containing the best documented data was included for analysis. Studies describing or evaluating the laparoscopic operative techniques without operative data were excluded. Data on operative, clamping and anastomosis times, hospital stay, mortality, complications and conversion were retrieved. Exclusion criteria were evaluated to identify which patient population would be suitable for laparoscopic surgery.

Study quality

Each article included was appraised by two reviewers using the critical review checklist of the Dutch Cochrane Centre [7] (Table 1). This list evaluates the quality of the study by using the following key statements which in the form of questions can be answered with yes (+), no (–) and uncertain (?).

1. For a clear definition of study population the aneurysm size and TASC (TransAtlantic Inter-society Consensus) classification or equivalent description for both aneurysm repair and occlusive disease must be plainly stated.
2. Selection bias could only be sufficiently excluded if information on the complete cohort under treatment was stated.
3. A clear description of method of intervention was defined as one that stated numbers and types of operative procedure (e.g. bifurcation or tube grafts, uni- or bilateral bypasses).
4. A clear definition of outcomes and outcome assessment was defined as one that stated operative and hospital data numerically.
5. Independent assessment of data was acceptable only if independent or blinded observers had performed data collection and evaluation.
6. Duration of follow-up was considered to be adequate only if follow-up during the entire hospital stay up to discharge was complete.
7. Selective loss to follow-up was suspected if excluded or converted patients were not accounted for in the study.
8. Important confounders and prognostic factors excluding the issues addressed in statements 1 and 2 were, for instance, change of exclusion criteria resulting from increasing experience and the learning curve.

Furthermore, each study was evaluated using a list of detailed study characteristics as proposed by the Meta-Analysis of Observational Studies in Epidemiology (Moose) group. [8] Studies were scored on 8 items. Each item was graded on a scale of 0 to 2 depending on the information available, so that the perfect study would have a maximum score of 16.

1. Consecutive series: 0=not reported, 1=not consecutive, 2=consecutive.
2. Prospective series: 0=not reported, 1=retrospective, 2=prospective.
3. Report on excluded patients: 0=not reported, 1=number only, 2=number and reason of exclusion.
4. Surgical indications: 0=not reported, 1=general description like occlusive disease or aneurysm, 2=details of extent of lesions (TASC) or aneurysm size.
5. Surgical procedures: 0=not reported, 1=total number only, 2=number of each procedure. (e.g. bifurcation or tube graft)
6. Conversion: 0=not reported, 1=number only, 2=number and reason of conversion.
7. Morbidity: 0=not reported, 1=number, 2=number and specifications of complications.
8. Mortality: 0=not reported, 1=number, 2=number and cause of death.

The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the manuscript as written.

Results

The initial search yielded 755 articles; 625 articles were excluded because they covered a topic other than laparoscopic surgery of the aorto-iliac tract. Ten papers were written in languages other than English or German (5 Czech, 3 French, 1 Italian, 1 Danish). Thirty-six experimental studies, comments, reviews, descriptions of complications and operative techniques were excluded. Sixty-six potentially eligible articles remained, [1 - 6, 9 - 68] including 14 case reports [1, 3, 9, 17, 23, 25, 31, 34, 43 - 45, 58, 66 and 67] and 6 small series. [4, 5, 15, 20, 52 and 56] Two studies described laparoscopic re-intervent on surgery after previous surgery [55 and 57] and were excluded, as they were not considered standard procedures. Several authors were over-represented in the selected studies. Only the largest, most complete series were used, leading to a reduction of 14 articles. [13, 14, 16, 18, 22, 27, 33, 35, 38, 42, 48, 49, 62 and 64]

In the remaining 30 articles, 8 hand-assisted (6 occlusive disease, 2 aneurysm), 6 laparoscopy assisted (3 occlusive disease, 3 aneurysm), 17 totally laparoscopic (11 occlusive disease and 6 aneurysm) and 2 robot-assisted series (1 occlusive disease and 1 aneurysm) were described. The total reported number of operated patients was 1044, 630 for occlusive disease and 414 for aneurysm repair. Data from these studies, sorted according to operating technique and disease (occlusive disease/aneurysm) are shown in Table 2 and Table 3.

Study Quality

All 30 selected studies were observational including 9 comparative studies (with contemporary series, [21, 26, 46, 50, 51 and 61] historical controls, [36 and 37] and endovascular repair [49]). Because of the heterogeneity of the studies (varying types of operative technique and surgical procedure) pooling of data was not considered appropriate. Quality assessment of the studies (Table 1) showed two important deficits in most studies: inadequate description of the study population (mainly for occlusive disease) and a suspected selection bias of patients. The total quality score of the description of the study characteristics is shown in the last column of Table 1. Although operative data are well documented, their quality is influenced if information on whether data were retrospectively or prospectively acquired and if patients were consecutively included is missing. The few comparative studies, [21, 26, 36, 37, 46, 50, 51 and 61] showed identical trends of longer operative time and shorter hospital stay.

Patient Selection

To identify which patients are potentially suitable candidates for laparoscopic vascular surgery, exclusion criteria were evaluated. The most frequently mentioned exclusion criteria were class 4 ASA (American Society of Anesthesiologists classification) patients or those with severe non-treatable coronary disease, extensive aortic calcification or associated visceral occlusive disease or who had undergone previous major abdominal surgery. In lapar scopic aneurysm repair, inflammatory and ruptured aneurysms were also mentioned as exclusion criteria. The more experienced authors did however operate in the presence of adiposity, concomitant visceral occlusive disease or if suprarenal clamping was necessary.

Conversion

In total, 78/1044 patients (7%) laparoscopy was converted to open surgery. The rate of conversion varied, with the highest number of conversions occurring in the smaller series. In series of >50 patients conversion rates were <5%, and in series of <20 patients up to 16%. In aneurysm repair the conversion rate was higher than in occlusive disease (39/630 vs 39/414). Reasons for conversion were: calcified aorta, bleeding from the cava, renal, or iliac veins or aorta, adhesions, the necessity of suprarenal clamping or inadequate exposure of the operative field due to collapse of the pneumo-peritoneum or the pneumo-retroperitoneum or other technical difficulties. Self-imposed operative time limits (aortic cross-clamping time of more than 2 hours and total operative time of more than 4 hours) were sometimes a reason for conversion. [2 and 55]

Clamping Time

Hand-assisted procedures had the shortest cross-clamping times, all <1 hour. Both laparoscopic-assisted and totally laparoscopic procedures reported clamping times varying from 54 to 146 minutes. Clamping times were a little shorter in operations for occlusive disease. Totally laparoscopic clamping times were at least 1.5 times longer than the comparative open series. [21, 26, 37 and 61]

Anastomosis Time

Anastomosis time was reported only in some of the totally laparoscopic procedures and varied from 30–60 minutes for procedures without a robotic system and 41–74 minutes with a robotic system.

Table 1. Quality assesment list of included studies

	Clear definition of study population ?	Can selection bias be excluded sufficiently?	Clear description of method of intervention?	Clear definition of outcomes and outcome assesment?	Independent assessment of outcome parameters?	Sufficient duration of follow-up?	Selective loss to follow-up?	Important confounders and prognostic factors identified?	Total quality score of description of study characteristics
Cau [67]	+	+	+	+	-	+	-	+	14
Dooner	-	-	+	-	-	+	-	+	10
Rouers [66]	-	-	-	+	-	+	-	+	14
Lin [55]	+	?	+	+	-	+	-	+	13
Olinde [56]	-	-	+	+	-	+	+	+	10
Coggia [25]	+	-	+	+	-	+	-	+	11
Remy [50]	+	-	+	+	-	+	-	+	13
Dion [30]	+	-	+	+	-	+	-	+	10
Alimi [14]	-	-	+	+	-	+	-	+	11
Said [51]	-	-	+	+	-	+	-	+	9
Barbera [17]	+	-	+	+	-	+	-	+	9
Nio [6]	+	+	+	+	-	+	-	+	13
Alimi [11]	+	+	+	+	-	+	-	+	14
Lacroix [44]	-	+	+	+	-	+	+	+	10
Fabiani [33]	+	-	+	+/-	-	+	+	+	6
Fourneaux [58]	+	-	+	+	-	+	+	+	12
Debing [26]	-	-	+	+	-	+	-	+	9
Wijtenburg [54]	-	-	+	+	-	+	-	+	11
daSilva [52]	-	-	+/-	+	-	+	-	+	11
Kelly [38]	-	-	+	+	-	+	-	+	11
Kolvenbach [41]	-	-	+	+	-	+	-	+	15
Coggia [59]	+	-	+/-	+	-	+	-	+	13
Coggia [24]	+	+	+	+	-	+	-	+	10
Kolvenbach [2]	+	+	+/-	+	-	+	-	+	12
Edoga [32]	+	-	+	+	-	+	+	+	12
Alimi [12]	+	+	+	+	-	+	-	+	14
Castronuovo [21]	+	-	+/-	+	-	+	-	-	13
Kline [39]	+	-	+	+	-	+	-	+	10
Ferrari [65]	+	+	+	+	-	+	-	+	16
Kolvenbach [40]	-	-	+	+	-	+	-	+	7

+= yes, -= no, ?= uncertain

Table 2. Occlusive disease. Operative data of included studies

	Year	N	Operative time (minutes)
Total laparoscopic surgery			
Cau [67]	2006	72(66abf,4auf)	216 +/-50*
Dooner	2006	13(abf)	390(320-480)nr
Rouers [66]	2005	30(30abf)	244+/-11*††
Lin [55]	2005	68(68 af)	199+/-31*
Olinde [56]	2005	22(20 abf)	267(199-365)†
Coggia [25]	2004	93(68abf,25auf)	240(150-450)†
Remy [50]	2005	21(21 abf)	240 (150-420)‡
Dion [30′]	2004	46abf/)	290+/-62*
		3if	193+/-58*
Alimi [14§]	2001	7(5abf,2auf)	351(295-420)‡
Said [51]	1999	7(7 abf)	390(180-600)‡
Barbera [17]	1998	24(11abf,5auf,7if,1tea)	250(150-450)†
Robot-assisted laparoscopic surgery			
Nio [6]	2005	8(8 abf)	405 (260-589)†
Laparoscopic-assisted surgery			
Alimi [11]	2004	58(52 abf,4 auf,1t,1tea)	238(140-420)‡
Lacroix [44]	1999	10(9 abf)	350(230-390)†
Fabiani [33]	1997	9(3 abf,4 auf)	160(90-240)‡
Hand-assisted laparoscopic surgery			
Fourneaux [58]	2005	46(45abf)	208(155-300)‡
Debing [26‖]	2003	13(7abf,4abi,1auf,1tea)	230(150-270)†
Wijtenburg [54#]	2003	25(2t, 1ai,19abf, 3auf)	180(120-290)‡
daSilva [52]	2002	18(18 af)	191(160-221)‡
Kelly [38]	2002	8(8 abf)	234(170-319)‡
Kolvenbach [41§]	2000	29(nr)	149+/-35.2*

* mean and standard deviation,† median and range, ‡mean and range, nr=not reported
t=tube repair, abi=aortobi-iliac bifurcation graft, abf=aortobifemoral bypass, auf=aortounifemoral graft, if=ileofemoral graft, tea=endarterectomy, ai=aortoiliac graft, aortofemoral, bif= bifurcated graft, § part of study, || AAA (3) and AIOD (10),

Operative Time

Operative time varied widely between both authors and laparoscopic techniques. Hand-assisted procedures had the shortest mean operative times, varying from approximately 2.5 to 4 hours. In laparoscopy-assisted techniques, both for aneurysm repair and occlusive disease, mean operative times of more than 4 hours were described, except for one study [39] which reports less than 3 hours (occlusive disease). In totally laparoscopic techniques the time varied from 4 to 6.5 hours. Operative times did not differ between aneurysm repair and

Clamping time (minutes)	Anastomosis time (minutes)	Hospital stay (days)	Mortality x/n	Conversion x/n
57+/-21*		8(5-42)‡	0/72	2/72
		7(3-14) nr	0/13	3713
66 +/-5*††	50 +/-3*††	5+/- 0,3*††	0/30	6/30
85+/-32*		6.3+/-2*	1/68	3/68
90(64-141)†	37(30-56)†	4(2-7)†	1/22	2/22
68(30-135)†	30(12-90)†	7(2-57)†	4/93	2/93
60(30-120)‡	60(30-120)‡	7 (5-30)‡	0/21	1/21
99+/-28*	47+/-13*	5(4-24) *	1/51	5/51
100+/-40*	55+/-13*	3.3+/-0.6*	0/3	0/3
128(75-170)‡		11(5-30)‡	0/7	0/7
59(45-110)‡		6(3-14)‡	1/7	0/7
70(55-120)†		(3-25)	0/24	4/24
111 (85-205)†	74 (40-110)†	8 (3-57)†	1/8	2/8
54(15-170)‡		8 (3-32)‡	2/58	1/58
		7(5-13)†		1/10
		(4-7)		2/9
28(15-55) ‡ **		6(3-26)‡	2/45	1/46
29(23-72)†		6(4-42)†	0/13	1/13
37(15-60)‡		7(4-15)‡	1/25	2/25
44(38-50)‡		7(5-9)‡	0/18	1/18
		4(3-5)‡	1/8	0/8
36.4+/-7.9*		4.3+/-2.2*		

AAA(10) and AIOD(15),,**e-s anastomosis 28(15-55); e-e anastomosis 69 (55-86),
†† converted patients operative time 232+/-24*, clamping time 57+/-13*, anastomosis time 37+/- 8*, hospital stay 12,1+/- 2,1*

occlusive disease. More recent studies report a shorter operative time than do the earlier studies. The robot-assisted technique was used in 18 patients in 2 studies. Kolvenbach reports operating times (mean 4 hours) equal to those of total laparoscopic aneurysm repair without the use of a robotic system.2 The other study on occlusive disease reported very long (median 5.5 hours) operative times. [6]

Table 3. Aneurysm repair. Operative data of included studies

	Year	N	Operative time (minutes)
Total laparoscopic surgery			
Cau [67]	2006	23(23t)	251+/- 57*
Coggia [59]	2005	30(13 t,17 bif)	255(170-410)†
Coggia [24]	2004	30(11 t,15 abi,4 abf)	290(160-420)†
Kolvenbach [2]	2004	37(nr)	227+/- 34*
Dion [30]	2004	7(6 abf, 1 t)	299+/-75*
Edoga [32]	1998	22(16 abf,4 abi)	391(180-600)‡
Robot-assisted laparoscopic surgery			
Kolvenbach [2]	2004	10(8 t,2 abi)	243+/- 41*
Laparoscopic-assisted surgery			
Alimi1 [2]	2003	24(12 t,3 abi,8 abf,1af)	238(155-360)‡
Castronuovo [21]	2000	60(60 bif)	462(90-690)‡
Kline [39]	1998	20(t)	246+/-55.2*
Hand-assisted laparoscopic surgery			
Ferrari [65]	2006	122	257+/- 70*
Kolvenbach [40]	2001	29(nr)	181(130-345)‡

* mean and standard deviation,† median and range,‡ mean and range t=tube repair, abi=aortobi-iliac bifurcation graft, abf=aortobifemoral bypass, auf=aortounifemoral graft, if=ileofemoral graft, tea=endarterectomy, ai=aortoiliac graft, aortofemoral, bif= bifurcated graft, nr=not reported

Morbidity

Reported complications included local wound problems (infection, seroma, dehiscence), respiratory and transient renal insufficiency, cardiac and mesenteric ischemia, splenic rupture, massive cholesterol embolization, graft thrombosis and bleeding. Five injuries of the ureter [10, 12, 21, 37 and 61] are mentioned. Limb graft thrombosis is reported 11 times. [10, 21, 28, 36, 40, 60, 65, 54 and 59] Six instances of anastomotic bleeding were reported. [10 - 12, 21, 28 and 36]

Mortality

Reported mortality rates, in total 26/1044 (2%) were in most series approximately 5% or less. Mortality in aneurysm repair was slightly higher than in occlusive disease (11/414 vs 15/630). Mortality was mainly due to postoperative cardiac ischemic events, followed by mesenteric ischemia.

Hospital Stay

In all but six [6, 10, 12, 22, 29 and 26] reports, mean hospital stay was one week or less, varying from 3 to 11 days, for both the total laparoscopic approach

Clamping time (minutes)	Anastomosis time (minutes)	Hospital stay (days)	Mortality x/n	Conversion x/n
101+/- 15*		6(4-12)†	1/23	7/23
80(35-110)†		9(5-37)†	1/30	1/30
78(35-230)†		9 (8-37)†	2/30	2/30
81 +/- 31*	53+/-9.0*	6.3+/-21.1*		6/37
109+/-52*	48+/-23*	6(3-32)*	0/7	1/7
146(6-286)‡		6(2-25)‡	2/22	2/22
96 +/- 22*	41+/-4*	7.3+/-2.4*		2/10
76 (42-160)‡		7(3-21)‡	1/24	4/24
112(43-286)‡		6(1-25)‡	3/60	3/60
		5.8+/-1.6*	0/20	2/20
76+/- 26*		4.4+/- 1.7*	0/122	9/122
57(44-90)‡		6(4-21)‡	1/29	

and the laparoscopic and hand-assisted approach regardless of the surgical procedure.

Discussion

This systematic review shows that since the introduction of laparoscopic surgery in 1993, only a small number of clinical studies on laparoscopic aorto-iliac surgery have been published. A variety of laparoscopic techniques, approaches and operative procedures were used and most studies were of an observational character and contained a limited number of patients. In addition we assumed a considerable selection bias in all series as the publications do not adequately describe the characteristics of the whole cohort of consecutive patients under treatment. This limits the full evaluation of laparoscopic surgery in relation to open or endovascular techniques.

In contrast to revolutionary changes in other fields of surgery, laparoscopic surgery has not become the minimal invasive alternative for the traditional xiphopubic incision in aorto-iliac surgery. The technical challenges presented by this advanced laparoscopic procedure probably preclude its wide implementation. Most surgeons start with relatively simple laparoscopic procedures for aorto-iliac occlusive disease. Operative procedures vary, but the majority of reported cases are aorto-bifemoral bypasses.

Operative times are long, but for this particular patient population it seems a safe (acceptable mortality/morbidity) and feasible (few conversions) procedure. As expected mid-term patencies of laparoscopic aorto-bifemoral bypasses [32 and 41] suggest results identical to those of open surgery. Over the years aorto-bifurcation bypasses with their good and durable patency rates have been the gold standard for treatment of TASC C and D lesions. [69] However, nowadays multilevel occlusive disease is also being treated by recanalization and percutaneous transluminal angioplasty/stenting.
Early results show that patency rates (one year primary assisted patency rate 88%) of these procedures are inferior to those of surgical bypass and re-intervention is frequently necessary. [70] However, percutaneous treatment remains a less invasive treatment option with fewer complications. If endovascular options are failing and alternative surgery is considered, laparoscopic aortobifemoral bypass might be a minimal invasive alternative.

Few series have been published on laparoscopic aneurysm repair. These studies report longer operative times and higher conversion rates compared to laparoscopic surgery for occlusive disease, although mortality is comparable with open procedures. Laparoscopic aneurysm repair appears to be more difficult than bypass surgery and is only done by a few surgeons.
This is in contrast to the wide implementation of endovascular repair of aortic aneurysms. This is a minimally invasive technique with a low mortality and is relatively easy to master. Taking this into consideration the results of laparoscopic aneurysm repair do not yet justify its broader implementation.

Long operative times are a major point of concern of laparoscopic surgery. As in most other fields of surgery, laparoscopic operative time is generally longer than its open counterpart, although current results are probably biased by the inevitable learning curve of this recently introduced technique. The question arises if every vascular surgeon should learn advanced laparoscopic procedures and indeed if these procedures are applicable to every patient. Their safety and feasibility have been demonstrated, but only in series of selected patients operated by dedicated surgeons.

The benefits of laparoscopic aorto-iliac surgery are found in the combination of its minimally invasive character (reduction of hospital stay and post-operative pain, earlier return to daily routines) and the durable results of conventional open surgery (less necessity for continuous follow-up).
However, the technique needs to become less demanding in order to make wider implementation possible. Technical difficulties of the vascular anastomosis need to be addressed e.g. by the development of a vascular stapler. The long learning curve can probably be shortened by extensive training in laparoscopic suturing before embarking upon patient procedures. The hand-assisted technique might further reduce the complexity of the procedure.

Conversion rates are difficult to interpret, because they are also influenced by other factors than the surgeons experience, e.g. patient selection, self-imposed operative time limits and surgical technique. However, the higher rate of conversion in small series is probably affected by a learning curve.
Only few centers have used robotic systems for laparoscopic aortoiliac surgery. [2 - 6]
The use of robotic systems has not yet reduced operative time in the few available series. [2 and 6]

Most studies had selection criteria for including patients for a laparoscopic technique, which sometimes changed with growing experience. More research is required to identify which patients are suitable candidates for laparoscopic surgery and to establish its additional value as the minimal invasive alternative to endovascular treatment.

Although a few dedicated centers are able to offer laparoscopic vascular surgery routinely, [26 and 54] it is too early to draw conclusions from the data currently available on the potential of this technique in order to justify its wider implementation.
In conclusion, laparoscopic aorto-iliac surgery is still in its infancy and is only practised in a few dedicated centers. Although safe and feasible, operative time is still long. The observational, non-comparative character and selection bias of most published series are their major limitations. More data are required to define the value of laparoscopic vascular surgery in comparison with endovascular and open surgery.

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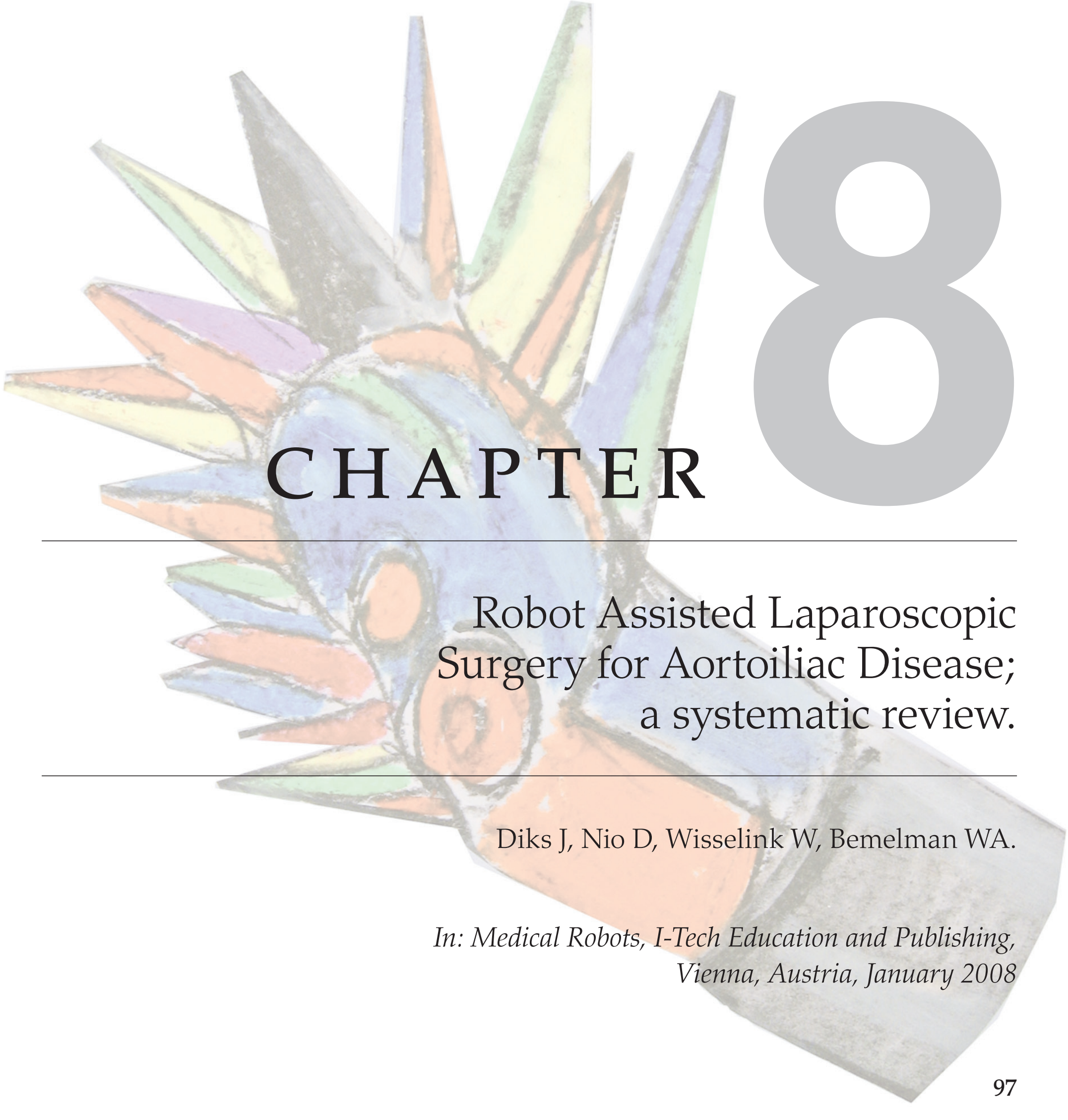

CHAPTER 8

Robot Assisted Laparoscopic Surgery for Aortoiliac Disease; a systematic review.

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Abstract

Background: robotic systems have been used to overcome the technical difficulties in laparoscopic aortoiliac surgery. In this chapter the outcomes of clinical and experimental studies using a robotic surgical system for treatment of aortoiliac disease are reviewed.

Methods: a computerized search was conducted in the medical databases Medline (from January 2000 to July 2007), Embase (from January 2000 to July 2007) and the Cochrane Database of Systematic Reviews. Operative times, ICU-stay, clamping time, blood loss, anastomosis time, time to resume to solids, hospital stay, mortality and conversion rates were described.

Experimental studies reporting on the creation of an aortic anastomosis with the robotic system were included.

Results: experimental studies on vascular anastomoses showed equal results when compared to laparoscopy using the Zeus system, whereas the da Vinci robot showed better anastomosis-times and more precise anastomoses when compared to laparoscopic surgery.

Five clinical studies were identified, with in total 70 patients. Operative time varied from 188 to 480 minutes, anastomosis time was 27 to 40.8 minutes. Total hospital stay differed between 4 and 7.3 days. An overall conversion rate of 7 (10%) was reported.

Conclusion: little data on robotic assisted laparoscopic surgery exist and the available data are of low quality. The application of robotic systems is feasible and safe, but no robust conclusions can be drawn with respect to comparison with conventional laparoscopic techniques or its cost effectiveness. Robotic assistance might facilitate an endoscopic vascular anastomosis and enhance laparoscopic surgery for aortoiliac disease, but comparative studies are necessary to support this hypothesis.

Introduction

Conventional aortoiliac surgery for either occlusive disease or aneurysm repair is accompanied by significant surgical trauma. Minimal invasive surgery reduces the tissue trauma and might result in reduced morbidity and mortality of aortoiliac surgery. Dion et al. pioneered towards the first total laparoscopic approach of the aortoiliac tract in 1993, by performing a laparoscopy assisted aortobifemoral bypass (Dion et al., 1993). Several open minded surgeons followed into his footsteps and several techniques for a total laparoscopic approach of aortoiliac disease were developed (Ahn et al., 1997; Alimi et al., 2000; Kolvenbach et al., 2001; Coggia et al., 2002). One-and-a-half decade later minimally invasive surgery of the aortoiliac vessels is performed only in a few centers around the globe. The slow implementation of laparoscopy assisted aortoiliac surgery can be explained by the technical difficulties encountered embarking on this kind of surgery. The most demanding parts of the total laparoscopic approach for aortoiliac disease are the creation of sufficient and stable exposure, and suturing of the aortic anastomosis. Various techniques are described to approach the abdominal aorta, such as a retro-peritoneal approach, use of the "apron" technique (a peritoneal 'flap' which is used to suspend the bowel), or a total transabdominal approach with extreme lateral rotation of the patient (Ahn et al., 1997; Alimi et al., 2000; Wisselink et al., 2000; Kolvenbach et al., 2001; Coggia et al., 2002; Dion et al., 2003).

Creation of the anastomosis requires a lot of skill, exercise and dexterity. Various authors reported to have been practicing for several months before gaining sufficient proficiency to implement vascular laparoscopy into everyday practice (Coggia et al., 2004; Olinde et al., 2005).
Robotic surgical systems have been developed to facilitate advanced laparoscopic procedures particularly suturing anastomosis as in aortoiliac laparoscopic surgery (Wisselink et al., 2002; Killewich et al., 2004; Desgranges et al., 2004; Kolvenbach et al., 2004; Ruurda et al., 2004; Nio et al., 2004; Nio et al., 2005a; Nio et al., 2005b; Stadler et al., 2006; Ishikawa et al., 2006; Mehrabi et al., 2006; Diks et al., 2007; Diks et al., submitted). This chapter reviews the use of robotic assistance in laparoscopic surgery of the aortoiliac vessels and its potentially additional value.

Methods

A computerized search was conducted in the medical databases Medline (from January 2000 to July 2007), Embase (from January 2000 to July 2007) and the Cochrane Database of Systematic Reviews, using the keywords "robot AND vascular surgery". The results were extended using a combination of the following Medical Subject Heading (MeSH) terms: robotics, aortoiliac disease, arterial occlusive disease, abdominal aneurysm, laparoscopy, robotic assistance, abdominal, experimental.
After identifying relevant titles, the abstracts of these studies were read to decide if the study was eligible. The full article was retrieved when the information in the title and/or abstract appeared to meet the objective of this review. A manual cross-reference search of the bibliographies of relevant articles was conducted to identify studies not found through the computerized search. The "related articles" feature of Pubmed was simultaneously used. Only articles in English language were included.

All experimental studies in which a robotic surgical system was utilized to perform an anastomosis of the aorta are included, evaluated and results described.

All clinical studies describing the use of a robotic surgical system for operating on the abdominal aorta were evaluated. Only papers describing the original patient group were selected. When duplicate material was reported in consecutive articles, the last publication – describing the largest patient group – was included. Data on operation time, ICU stay, clamping time, blood loss, anastomosis time, time to resume oral diet, total hospital stay, mortality and complication rate were identified and evaluated.

Results

Experimental studies:

Five experimental studies were included in which a laboratory setup model was used to perform a vascular anastomosis. These studies included two training box models (Nio et al., 2004; Nio et al., 2005b), one human cadaver study (Ishikawa at al., 2006), two porcine models (Ruurda et al., 2004; Mehrabi et al., 2006) and one rat model (Mehrabi et al., 2006).

Either the Zeus (Nio et al., 2004; Nio et al., 2005b) – or the daVinci surgical system (Ruurda et al., 2004; Mehrabi et al., 2006; Ishikawa et al., 2006) was used.
In the training box models, the Zeus robotic system (n=40) was compared with a conventional laparoscopic approach (n=40) to conduct a vascular anastomosis. Results showed no significant benefit of the use of the Zeus robotic system in operative time, surgical efficacy and learning curve.
The human cadaver case study described replacement of the thoracic aorta with assistance of the daVinci surgical system (n=1). It reported the feasibility of a thoracic aortal tube replacement with both the proximal and distal anastomoses being conducted in less than 20 minutes each.

In the porcine model, the da Vinci surgical system was used to compare robotic assisted with totally laparoscopic abdominal aortic tube replacement (n=20 vs n=20). The authors concluded that robotic assistance is superior to conventional laparoscopic techniques, because of shorter anastomotic- and clamping times and less blood loss (respectively 22 vs 40 min, $p<0.01$; 63 vs 106 min, $p<0.01$ and 55 vs 280 ml, $p<0.01$). At autopsy the robotic anastomoses showed to be more precise, with less space between consecutive stitches (> 3 mm space between stitches was found in 0/20 vs 12/20 anastomoses).

In a porcine/rat model, the learning curve of an aortic anastomosis using the daVinci surgical system was described. The authors used a training module (n=4) in which an aortic tube replacement was performed in a pig, subsequently in four rats and finally in another pig. The first aortic tube replacement was compared to the last one and a learning curve in the rat model was described. They demonstrated that after training the time to perform an aortic anastomosis was significantly reduced (25:19 vs 12:29 min:sec, $p<0,05$). The authors concluded from this study that robotic assistance has a steep learning curve for conducting an aortic anastomosis.

Patient series:
Five clinical studies were identified (total number of patients: n=70). These studies included one case-report (Killewich et al., 2004), one small case-series (n=5) (Desgranges et al., 2004) and three larger series from Kolvenbach (n=10), Stadler (n=30) and Wisselink (n=24) (Kolvenbach et al., 2004; Stadler et al., 2006; Diks et al., submitted). Of one series earlier results were reported in separate papers (Nio et al., 2005a; Diks et al., 2007). In these studies, either the Zeus (Computer Motion, Santa Barbara, CA, USA) (n=15) or the daVinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA) (n=55) was used to construct aortic anastomoses in surgery for aortoiliac occlusive – or aneurysmal disease (Table 1). Operative times varied from 188 to 480 minutes. ICU-stay, reported only in some of the cases, varied from 1 to 2.1 days. Clamping time was reported from 54 to 95.9 minutes. Blood loss varied between 320 and 1000 milliliters. Anastomosis time is reported inconsistently, but when reported it varied from 27 to 40.8 minutes. The time to resume a normal diet varied between 1.3 and 3 days. Total hospital stay varied from 4 to 7.3 days. One of the 70 reported patients died postoperatively. Seven of the 70 patients were converted to open surgery (10%). Reasons for conversion were either technical difficulties with the robotic system (n=4) or an unstable operative field (n=3). The technical difficulties with the robotic system consisted of failure of the robotic system and interference of the robotic arms outside the patient (Desgranges et al., 2004; Kolvenbach et al., 2004; Diks et al., submitted).

Some of the studies described patient selection criteria for robot assisted laparoscopic surgery. Patients with replacement of infected prostheses, with prior abdominal surgery, with redo-surgery of occluded prostheses and with class 4 ASA (American Society of Anesthesiologists) were generally excluded (Diks et al., 2007).

Tables

table 1: operation requirement

	Number of patients	Indication for surgery	Robotic system	Conversion (n)	Operative time (minutes)	Anastomosis time (minutes)	Clamping time (minutes)	Blood loss (ml)	ICU stay (days)	Resume diet (days)	Hospital stay (days)
Killewich	1	AOD	dV	0/1	480	X	65	500	X	2	4 (po)
Desgranges	5	AOD	dV	1/5	188	X	75 (± 28)	540	X	X	8 (po) (± 2.4)
Kolvenbach	10	AAA	Z	2/10	242.5 (± 40.5)	40.8 (± 4.1)	95.9 (± 21.6)	X	2.1 (± 1.0)	1.3 (± 0.6)	7.3 (± 2.4)
Stadler	30	AOD / AAA	dV	0/30	236 (180-360)	27 (20-60)	54 (40-120)	320 (100-1500)	1.8 (1-5)	2.5 (2-4)	5.3 (4-10)
Diks	24	AOD	Z / dV	4/24	355 (225-589)	40 (21-110)	77.5 (25-205)	1000 (100-5800)	1 (1-16)	3 (1-4)	5 (3-57)

dV: da Vinci
Z: Zeus
AOD: Aortoiliac Occlusive Disease
AAA: Abdominal Aortic Aneurysm
X: not reported
po: post operative

Discussion

Two contradictory conclusions emerge from the experimental studies. When the Zeus robotic system was used, no additional value in creating a vascular anastomosis was observed. However, the Zeus system, which was used in these experiments, was not equipped with microwrist instruments yet. In studies where the da Vinci robotic system was used, all authors concluded robotic assistance to be helpful. They noted operation times to be significantly shorter and the anastomoses to be significantly more precise when compared to conventional laparoscopy. A conclusion that the da Vinci robot would be superior to the Zeus could be speculated. This is consistent with results found in other experimental studies which compared the Zeus with the da Vinci robotic system (Sung & Gill, 2001; Dakin & Gagner, 2003). This observation is irrelevant, since the Zeus robot is no longer commercially available.

Only a few patient series were identified. The number of reported patients was small and the study quality of most series was low. Inclusion criteria, study population and individual patient data were poorly described. Since a variety of surgical procedures was performed, patient data could not be pooled to one large series. For this reason no robust conclusions can be made with respect to patient outcomes of robotic assisted aortoiliac surgery compared to conventional laparoscopic surgery.

This review shows that robot assisted laparoscopic surgery (RALS) is an under-explored technique when it comes to minimally invasive treatment for aortoiliac disease. Where RALS has been used in various fields of surgery, such as cardiac-, general-, gynecologic-, thoracic-, and urologic surgery, vascular surgery remains an area in which robotic surgery has yet to establish its current role.
Reported series show that RALS is a feasible and safe procedure, with operative- and clamping times which are comparable to larger series of totally laparoscopic aortoiliac surgery (Coggia et al., 2004; Dion et al., 2004; Olinde et al, 2005). Conversion rate was less when compared to some smaller series in laparoscopic vascular surgery (Barbera et al., 1998; Rouers et al., 2005; Dooner et al., 2006). Outcome parameters e.g. post operative pain and incidence of incisional hernias were not studied, so no conclusions can be made.

An alternative minimally invasive approach, viz. endovascular therapy, is gaining rapidly in popularity in vascular surgery. The implementation of endovascular therapy has been broadened over the last decade and it has shown good results in patient outcome. Nevertheless, long-term results of endovascular treatment still do not surpass those of surgical bypass (Rzucidla et al., 2003). For aneurysm repair, the promising early results favouring endovasculair compared to open repair are not sustained in time. The applicability of endovascular therapy is also limited by the extension of occlusive lesion in aortic occlusive disease and the anatomic suitability in aneurysmal disease. Since (robot assisted-) laparoscopic surgery is less bound by vascular anatomy and the same reconstruction is obtained as in open surgery, the solid and durable results of open repair are likely extrapolated to the laparoscopic approach.
The advantages of robotic systems consist of a 3D view and articulating instruments, providing increased degrees of freedom of movement over

conventional laparoscopic instruments. These aspects seem helpful when performing complex endoscopic procedures such as suturing a vascular anastomosis. Furthermore, RALS has shown to overcome a long learning curve which is associated with laparoscopic vascular surgery (Coggia et al., 2004). Even with few numbers of patients, clamping - and anastomosis time reduced significantly after only eight patients (Diks et al., 2007). These results show that robotic assistance can help conventional vascular surgeons to start up laparoscopic surgery, even without prior extensive laparoscopic experience.

The use of a robotic system does not obviate training and exercise in advanced laparoscopic techniques. (Laparoscopic) surgical proficiency is established by education and training. A robotic system must be considered as a tool to improve the performance of the surgeon, not be a means to obviate education and training. Several laparoscopic vascular surgeons have shown to suture vascular anastomoses with great proficiency (Coggia et al., 2004; Kolvenbach et al., 2004).
So far, no totally robotic vascular procedures have been described. Robotic systems were only used to create the aortic anastomosis, while conventional laparoscopic techniques were used to approach the aortoiliac vessels. The larger part of the operation however, consists of conventional laparoscopic aortic dissection. Criticasters might argue that since the robotic system is merely used to create the vascular anastomosis, the time advantage compared to conventional laparoscopic suturing is limited. It has to be established whether the purchase of robotic systems and the use of extremely expensive disposables is cost effective compared to laparoscopic suturing of the anastomosis. A benefit of using robotic systems for the total operation has not been evaluated.

Otherwise it has to be considered that if the case volume is insufficient for maintaining these specific endoscopic skills, a robotic system, when available, might be useful to ensure a high quality vascular anastomosis.
It has been shown that RALS for aortoiliac disease is still in a very early stage. Operative times, although comparable to conventional laparoscopic series (Nio et al., 2007), still surpass those of open surgery by far. Furthermore, no research has been done to investigate the cost-effectiveness of a robotic surgical system. It is the task of dedicated centers to answer this research question, ideally in the setting of a randomized clinical trial, in order to provide scientific evidence for the additional value of robotic assistance in laparoscopic vascular surgery.
Meanwhile, with new developments at the horizon – such as an intravascular stapler (Shifrin et al., 2007) – it is yet to see whether this bridging technology has a future in the field of minimally invasive treatment for aortoiliac disease.

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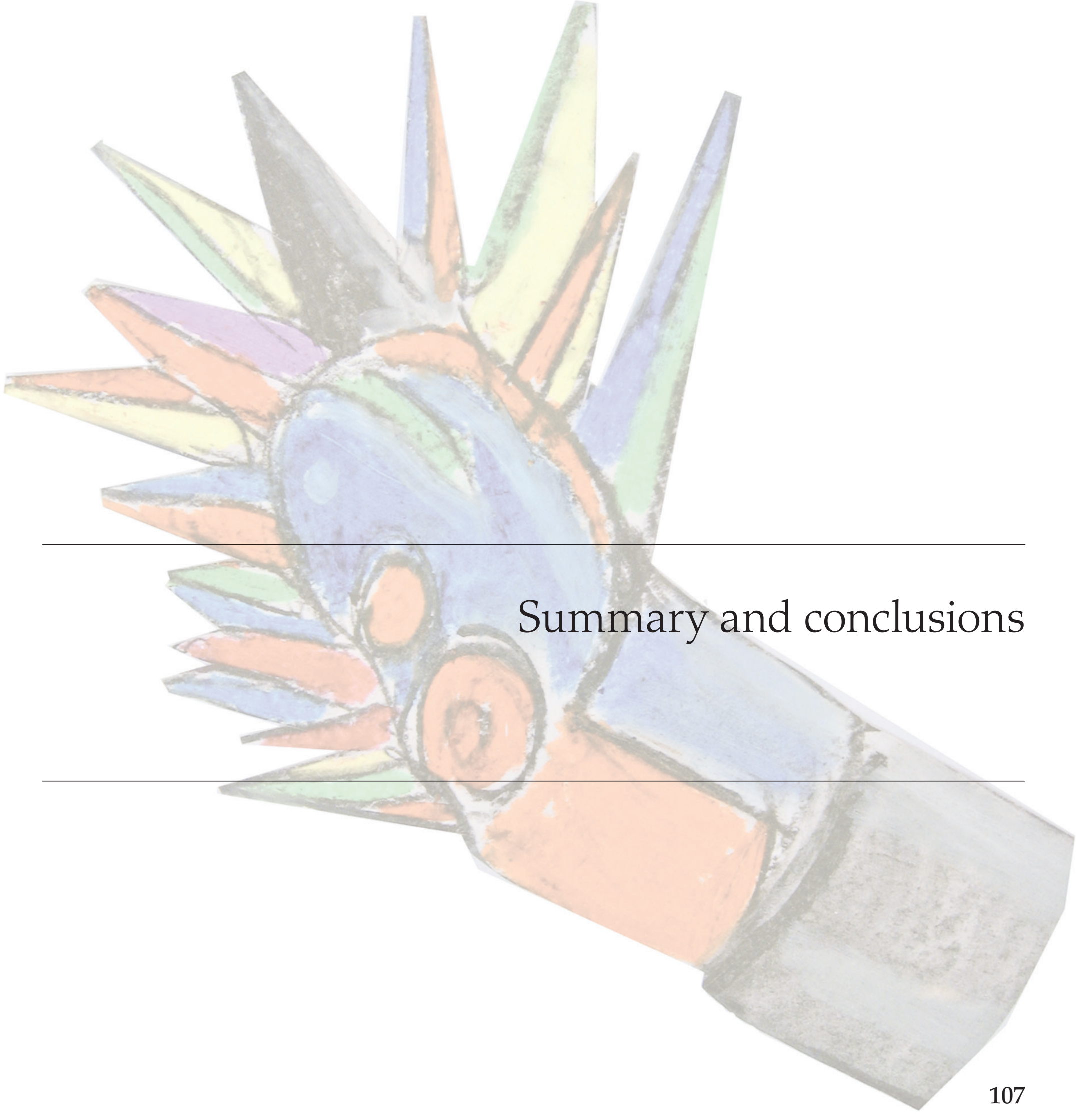


Summary and conclusions

Summary

This study was performed to evaluate the applicability of robotics in aortic surgery. The gold standard in aortic reconstructive surgery remains access by means of a large midline xipho-pubic incision. However, this open approach is intrinsically associated with a variety of potential complications such as post-operative ileus, post-operative pain, wound infections and incisional hernias. A less invasive approach such as laparoscopic surgery conceptually could decrease these sequelae. Laparoscopic surgery however, is known to have a number of limitations. A combination of limited degrees of freedom, 2-dimentional vision, an un-natural working-axis, the fulcrum-effect and limited haptic feedback require a great deal of training and expertise before complex laparoscopic procedures can be safely performed in a timely manner.
Aortobifemoral bypass for aortoiliac occlusive disease is, when approached laparoscopically, a technically very challenging operation. The most demanding part of the operation is considered to be the aortic anastomosis during which the operative field is confined to a few square centimeters and the lack of degrees of freedom is most noticeable. Here, robotic assistance may help to overcome the technical difficulty, thus making laparoscopic aortic surgery accessible to more than a few pioneers.

In **chapter two**, evaluation of a newly developed device – the minimal invasive manipulator (MIM) – is illustrated. This MIM consists of two purely mechanical arms, which can be used as laparoscopic instruments and allow seven degrees of freedom. The MIM moves in a comparable way to the robotic system, but doesn't have motorized - or computerized parts. Consequently, its haptic feedback is similar to that of conventional laparoscopic instruments. By comparing basic skills between the MIM and standard laparoscopic tools, an additional value of extra degrees of freedom could be established.
In this experiment, 30 students were randomized in two groups and were assigned to do 4 different tests with either the MIM or laparoscopic needle holders. The test consisted of repositioning coins, passing a rope between the two instruments, passing a suture through 8 rings and tying a surgical knot. An independent researcher performed a quantitative time-action analysis by observing the recorded tests.

A significant difference between actions was shown in favor of the MIM-group in most exercises and a significant difference between failures was shown in favor of the MIM-group in the coin- and rope-passing exercise. No significant difference was shown in total time to complete the exercises.

Results from this experiment show that, even though no time-difference was seen, a more accurate performance can be obtained with instruments using additional degrees of freedom. Technically demanding procedures, performed in a limited space, may benefit from instruments equipped with this technique.

One of the main disadvantages of currently available robotic systems is the lack of haptic feedback. Whereas in conventional laparoscopic surgery, the surgeon has some kind of haptic feedback through the laparoscopic instruments, this feedback lacks completely in robotic surgery. The instruments are separated from the surgeon, whose movements in the control panel are routed to the motorized instruments by means of computerized technology.
In **chapter three**, a study is described in which we tested whether manipulation of suture material with robotic instruments would affect the integrity of the suture material thus causing it to loose strength. In our laboratory experiments it showed to be virtually impossible to complete a vascular anastomosis without manipulating the suture several times. The potential hazard of damaged sutures may very well be especially important when constructing a vascular anastomosis.We examined to what extent the suture was damaged after robotic manipulation and whether the type and texture of suture material would effect the outcome.

A total of 180 sutures of three different materials (Prolene, ePTFE and Ethibond) in three different sizes (3-0, 4-0, 5-0) were manipulated with the robotic system. 90 unmanipulated sutures served as a control group. Subsequently, the sutures were tied onto a Servohydrolic Universal Testing Machine (SUTM) and pulled until they ruptured. Pulling strength and place of rupture was recorded and frequency of breaks at a manipulation-point and the maximum applied force (N) before the suture broke were used for statistic analysis.
Both the Prolene sutures as the Ethibond sutures showed significant loss of strength and broke significantly more often at manipulation-points. ePTFE sutures did not show a significant loss of strength after manipulation.
After conducting this experiment, we decided to use ePTFE sutures during robotic surgery.

Chapter four reports of our first clinical series with robot assisted laparoscopic surgery for aortoiliac occlusive disease. A series of eight patients is described, of which the first five patients were operated on with a Zeus-Aesop system. This system was on loan for a limited period of time and a year later our hospital acquired a da Vinci robotic system with which the latter three patients were operated on.

Two different techniques were used for aortic exposure; the ‘apron’ technique and a retroperitoneal approach. Complications occurred on two occasions and a conversion to open surgery had to be done. One patient died, after an uneventful operation, on postoperative day 3 due to a massive myocardial infarction.
Post-operative data showed a median operative time of 405 minutes (range 260 – 589), an aortic clamping time of 111 minutes (range 85 – 205), anastomosis time of 74 minutes (range 40 – 110), blood loss of 900 milliliters (range 200 – 5800) and a hospital stay of 7.5 days (range 3 – 57).
This first series showed a feasible and save technique, however operative times were still too long and more experience had to be obtained.

After expanding our series to 17 patients, a learning curve could be described when comparing the first series of 8 patients to the latter 9. This learning curve has been illustrated in **chapter five**.
Comparing both series, a significant difference in aortic clamping time (57.5 minutes versus 111 minutes ($p < 0.01$)) and anastomosis time (34 minutes versus 74 minutes ($p < 0.01$)) was seen. No other significant differences were shown, but these outcomes describe a clear learning curve for the robotic anastomosis. Furthermore, a different strategy in laparoscopic approach towards the abdominal aorta is described. Using extreme patient rotation (85 - 90°) and a transabdominal approach, obtaining a stable operation field seems more secure.

Chapter six describes a case control study comparing our outcomes with robot assisted aortobifemoral bypass to the gold standard of open aortobifemoral bypass. In a retrospective study we identified a group of 30 patients who had undergone open surgery in our institution prior to implementation of the robotic system. The outcomes were compared to our robot assisted group of 24 patients.Groups were similar in BMI, cardiovascular risk factors, ASA class en TASC score.
Operative time and aortic clamping time were significantly shorter in the open group, as could be expected. Blood loss was comparable between both groups.
Post-operative outcomes showed a significant favor towards the robot assisted group: ICU stay was 1 day (range 1 – 16) versus 2 days (range 1 – 6) ($p < 0.001$), resumption of normal diet was on postoperative day 2 (range 2 – 32) versus day 5 (range 3 – 24) ($p < 0.001$), resumption of ambulation was on postoperative day 3 (range 1 – 43) versus day 4 (range 2 – 8) ($p < 0.001$) and total hospital stay was 6 days (range 3 – 57) versus 14.5 days (8 – 88). Given results show a considerable improvement in post-operative patient outcome after implementation of robot assisted laparoscopic aortic surgery in our institution.

In **chapter seven** a systematic review is described, in which an overview of published series on laparoscopic vascular surgery is included. First publications date from 1993 and only 30 original patient series were published since.
Included in this review were series of laparoscopy assisted -, hand assisted laparoscopic -, total laparoscopic - and robot assisted laparoscopic surgery for both aortic occlusive - and aortic aneurysmal disease, with more than five patients.

Published series show long operative and aortic clamping times. Furthermore, considerable bias due to patient-selection seems to make it more difficult to interpret given results.
A general conclusion in these series was that laparoscopic vascular surgery is a time-consuming and technically challenging procedure. It should only be performed in highly specialized centers and by dedicated surgeons. Only two series of robot assisted laparoscopic surgery were included.

Finally, **chapter eight** reports on a systematic review on robotic vascular surgery. This review was performed to identify all studies published to date without exclusion criteria. A total of five experimental studies and five clinical studies, in which both the Zeus-Aesop system and the da Vinci robotic system were used, were identified and included in this review.
Experimental studies describe robotic surgery to perform an aortic anastomosis. Results show no significance when comparing the Zeus-Aesop system to laparoscopic techniques, whereas the da Vinci robotic system performed more accurate anastomoses in significant shorter time.

Clinical studies described a total of 70 patients, treated for both aortoiliac occlusive and aneurysmal disease. Results show an operative time of between 188 and 480 minutes, with an anastomosis time of 27 to 40.8 minutes. Total hospital stay varied from 4 to 7.3 days, conversion rate was 10%.
This final chapter shows the lack of evidence for robot assisted aortic surgery; published series are few and small. They do, however indicate the safety and feasibility of robot assisted aortic surgery.
Prospective, randomized research will have to establish the role of robotics in aortic surgery in the future.

Overall Conclusions

- Laparoscopic surgery benefits from instruments providing extra degrees of freedom. This phenomenon, which has been clearly demonstrated in several basic skills studies using the minimal invasive manipulator, appears to be even more obvious during performance of advanced laparoscopic tasks.

- Robot-assisted construction of an aortic anastomosis is technically demanding and is virtually impossible to be completed without instrument manipulation of the suture. Certainly in view of the lack of haptic feedback in current robotic systems, consideration of type and texture of the suture-material to be used is essential to ensure a safe and durable anastomosis.

- Robot assisted laparoscopic surgery for aortoiliac occlusive disease is a safe and feasible technique, with acceptable patient-outcomes. Nevertheless, when first implementing this technique considerable operative times and aortic clamping times have to be anticipated.

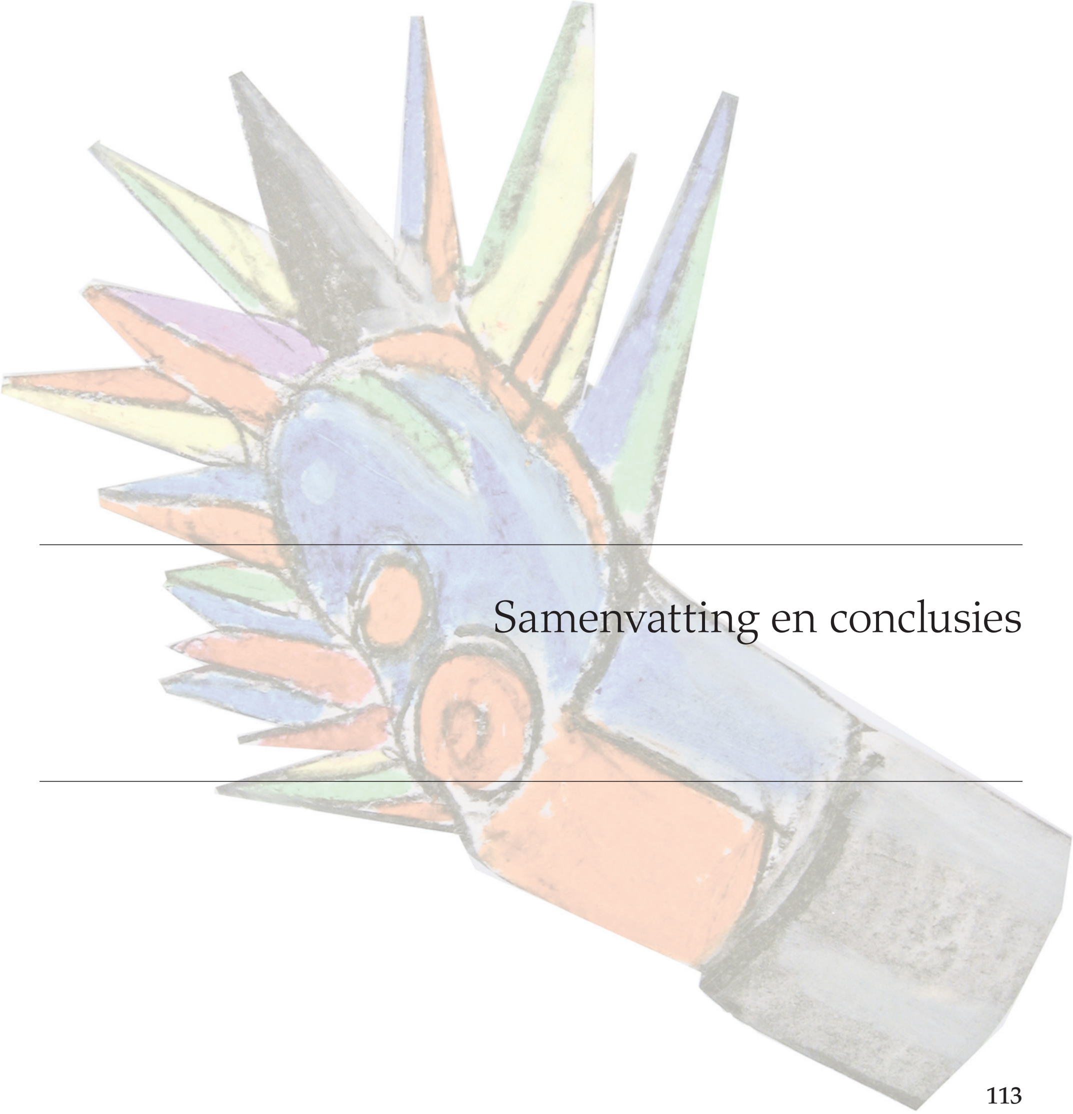
- Robot assistance in laparoscopic aortic surgery provides a considerable shortening of the learning curve as compared to conventional laparoscopic aortic surgery.

- When performing a laparoscopic dissection of the abdominal aorta, various techniques are at hand. The safest and most stabile technique appears to be a transabdominal approach with extreme patient-rotation (85-90°).

- When compared to open surgery for aortoiliac occlusive disease, robot assisted laparoscopic surgery requires longer operative times, but postoperative outcomes are significantly better.

- The paucity of published series on laparoscopic aortic surgery is a mere indication of the technical difficulty of this technique and its inherent long learning curves.

- Robotic vascular surgery is a promising new mimimally invasive alternative to open and endovascular surgical techniques. Although feasibility and safety have been demonstrated, to date the literature counts very few systematic studies and, to establish its definitive role in aortic surgery, more research has to be performed.



Samenvatting en conclusies

ROBOT GEASSISTEERDE AORTACHIRURGIE

Samenvatting

Aorta-chirurgie is volgens de gouden standaard nog altijd een zeer invasieve procedure, waarbij toegang tot de abdominale aorta verkregen wordt door middel van een grote buikwand-incisie. Deze chirurgie gaat vaak samen met uitgebreide problematiek, zoals wondinfecties, littekenbreuken, lange opnametijden en aanzienlijke post-operatieve pijn.
Een moderne vorm van opereren is laparoscopie, de zogenaamde 'sleutel-gat-operaties'. Hierbij wordt de buikholte van binnenuit opgeblazen met gas en vervolgens worden een camera en chirurgische instrumenten in de buikholte gebracht door zogenoemde 'sleutelgaten' in de buikwand. Bij deze manier van opereren wordt er minder letsel toegebracht en bestaat er minder kans op wondinfectie en littekenbreuken. Over het algemeen hebben patiënten minder pijn en gaan ze eerder weer naar huis en aan het werk.
Echter, er bestaan ook nadelen aan deze manier van opereren. Zo is het een onnatuurlijke benadering van het operatiegebied, er wordt gebruik gemaakt van een monitor met 2D-visie en de instrumenten hebben maar beperkte bewegingsvrijheden. Dit maakt dat de chirurg zeer uitgebreid geoefend moet zijn en ruime ervaring moet hebben om complexe operaties uit te voeren.
Aorta-chirurgie is bovendien zelfs voor een laparoscopisch behendig chirurg zeer complex, voornamelijk vanwege de anastomose (vaatnaad) die gemaakt moet worden tussen de aorta en de prothese. Hierbij is het operatiegebied slechts een paar vierkante centimeters en moet er zeer nauwkeurig gewerkt worden om een anastomose te maken die niet lekt. Bij het toepassen van laparoscopische chirurgie op deze ingreep, worden de nadelen ervan het meest duidelijk.

Recentelijk wordt er op groeiende schaal gebruik gemaakt van robot-chirurgie. De gebruikte 'robot-systemen' bestaan uit een karretje met daarop 3 of 4 robotarmen, waarin een camera en operatie-instrumenten geplaatst worden. Deze camera en instrumenten worden via 'sleutelgaten' in de buikholte gebracht en aangestuurd door de chirurg van achter een console. De voordelen bestaan onder andere uit een natuurlijke werkhouding voor de chirurg, 3D-visie van het operatiegebied in de buikholte en volledige bewegingsvrijheid van de instrumenten, welke zijn uitgerust met een 'mini-polsje'. Deze voordelen zouden er wel eens voor kunnen zorgen dat operaties die technisch té moeilijk zijn om laparoscopisch uit te voeren, met behulp van robot-chirurgie tóch via een 'sleutelgat-procedure' gedaan kunnen worden.

In hoofdstuk twee wordt een nieuw ontwikkeld apparaat voor het uitvoeren van 'sleutelgatoperaties' – de minimal invasive manipulator (MIM) – geëvalueerd.

De MIM bestaat uit twee mechanische armen, welke kunnen worden gebruikt als laparoscopische instrumenten, maar volledige bewegingsvrijheid hebben (zes beweging-graden in plaats van vier). De MIM beweegt in een vergelijkbare manier als een robot-systeem, maar heeft geen computer-gestuurde onderdelen. Als gevolg hiervan, is de gevoelsterugkoppeling vergelijkbaar met die van gewone laparoscopische instrumenten. Door basale oefeningen tussen de MIM en standaard laparoscopische instrumenten te vergelijken, kon een toegevoegde waarde van de extra beweging-graden bepaald worden.
In deze studie werden 30 studenten gerandomiseerd in twee groepen en werden ze toegewezen om 4 verschillende testjes te doen ofwel met de MIM, ofwel met normale laparoscopische instrumenten. De testjes bestonden uit het herpositioneren van muntjes, het overpakken van een lint tussen twee instrumenten, het leiden van een naald en draad door 8 ringen en het knopen van een chirurgische knoop. Een onafhankelijke onderzoeker deed vervolgens een kwantitatieve tijd-actie analyse, door middel van het bestuderen van opname-video's van de testjes.
Een significant verschil in aantal acties werd aangetoond in het voordeel van de MIM-groep in de meeste oefeningen en een significant verschil tussen het aantal fouten werd aangetoond in het voordeel van de MIM-groep in het muntjes- en lint-experiment. Geen significant verschil werd er gezien in totale tijd om de oefeningen af te ronden.
Resultaten van dit experiment laten zien dat, ondanks dat er geen verschil in tijd aangetoond werd, er een meer accurate uitvoering van de oefeningen behaald werd met instrumenten, uitgerust met extra beweging-graden. Technisch moeilijke ingrepen, uit te voeren op een klein operatiegebied, zouden voordeel kunnen hebben bij het gebruik van vergelijkbare instrumenten.

Eén van de grootste nadelen van de huidige robot-systemen is het ontbreken van gevoelsterugkoppeling. Zoals er in normale laparoscopische chirurgie ten minste énige vorm van gevoelsterugkoppeling bestaat, zo ontbreek deze compleet bij de robot-chirurgie. De instrumenten zijn gescheiden van de chirurg, wiens bewegingen in de console worden doorgegeven aan de gemotoriseerde instrumenten door middel van computer-technologie.

In hoofdstuk 3 wordt een studie beschreven waarin er getest werd of het vastpakken van hechtmateriaal met robot-instrumenten de integriteit van het materiaal zou beinvloeden, zodat uiteindelijk de kracht ervan zou afnemen. In onze laboratorium-experimenten werd duidelijk dat het praktisch onmogelijk is om een anastomose te hechten zonder de hechting enige malen vast te

pakken. Het potentiële gevaar van een beschadigde hechtdraad zou wel eens éxtra belangrijk kunnen zijn bij het aanleggen van een aorta-anastomose.
We onderzochten in hoeverre de hechtdraad beschadigd was na het vastpakken met de robotinstrumenten en of een verschil in type en samenstelling van de hechtdraad nog uitmaakt.
Totaal werden er 180 hechtdraden van drie verschillende materialen (Prolene, ePTFE en Ethibond) in drie verschillende maten (3-0, 4-0 en 5-0) vastgepakt met robot-instrumenten. Een controlegroep bestond uit 90 ongemanipuleerde draden.
Vervolgens werden de draden vastgemaakt aan een hydrolisch test-apparaat, welke net zo lang aan de draden trok werd tot ze braken. De trekkracht en plaats van breuk werden genoteerd en de frequentie van breuken op een manipulatie-punt en de maximaal toegediende trekkracht (N) werden gebruikt voor statistische analyse.
Zowel de Prolene hechtingen als de Ethibond hechtingen lieten een significant verlies van stevigheid zien en broken significant vaker op een manipulatie-punt. ePTFE hechtingen lieten geen verlies van stevigheid zien. Na dit experiment, hebben wij besloten enkel ePTFE hechtingen te gebruiken tijdens robot-chirurgie.

Hoofdstuk vier beschrijft onze eerste klinische serie van patiënten, geopereerd door middel van robot geassisteerde laparoscopische chirurgie. Deze patiënten leden allen aan aortailiacaal occlusief vaatlijden; een ziekte waarbij de overgang tussen de aorta en de beenslagaderen verkalkt is geraakt en de patiënten last hebben van etalagebenen (lage graad ziekte) of zelfs niet genezende wondjes op de benen / voeten (hoge graad ziekte). De therapie hiervoor is het aanleggen van een bypass tussen de aorta en de beenslagaderen.

Er wordt een serie van acht patiënten beschreven, waarvan de eerste vijf patiënten met een Zeus-Aesop systeem geopereerd zijn. Dit systeem was voor een bepaalde periode aan ons ziekenhuis uitgeleend en een jaar later werd er een da Vinci robotsysteem aangeschaft, waarmee de laatste drie patiënten van deze serie geopereerd werden. Er werden twee verschillende technieken gebruikt om de aorta te benaderen; de 'apron' techniek, waarbij de darmen in een soort 'schort' van het peritoneum (buikvlies) opgehangen worden, en een retroperitoneale benadering (achter het buikvlies langs).

In twee gevallen kwamen er complicaties voor en moest er geconverteerd worden naar open chirurgie. Eén patiënt overleed, na een ongecompliceerde operatie, op dag 3 postoperatief aan een hartaanval. Post-operatieve data laten een mediane operatietijd van 405 minuten zien (range 260 – 589), een aorta-

klemtijd van 111 minuten (range 85 – 205), een anastomosetijd van 74 minuten (range 40 – 110), bloedverlies van 900 milliliter (range 200 – 5800) en een ziekenhuisverblijf van 7.5 dagen (range 3 – 57).
Deze eerste serie liet een haalbare en veilige methode zien, echter de operatietijden waren nog te lang en er moest meer ervaring verkregen worden.

Nadat we onze serie verder uitgebreid hadden tot 17 patiënten kon er een leercurve beschreven worden, door de eerste serie van 8 patiënten te vergelijken met de laatste 9 patiënten. Deze leercurve wordt beschreven in hoofdstuk vijf.
Door beide series te vergelijken werd een significant verschil in aorta-klemtijd (57.5 minuten versus 111 minuten ($p < 0.01$)) en anastomosetijd (34 minuten versus 74 minuten ($p < 0.01$)) gezien. Er werden geen andere significante verschillen gezien, maar deze resultaten illustreren een duidelijke leercurve voor de robot-geleide anastomose.
Bovendien wordt een alternatieve benadering van de abdominale aorta beschreven. Door het gebruik van extreme patiënt-rotatie (85 - 90°) en een trans-abdominale benadering, lijkt het verkrijgen van een stabiel operatiegebied beter haalbaar.

Hoofdstuk zes beschrijft een case control study, waarin de uitkomsten van robot geassisteerde aortobifemorale bypass vergeleken worden met de gouden standaard; open aortobifemorale bypass. In een retrospectieve studie werd er een groep van 30 patiënten beschreven, welke open aortachirurgie hadden ondergaan in ons ziekenhuis vóórdat het robotsysteem gebruikt werd. Deze uitkomsten werden vergeleken met onze robot geassisteerde groep van 24 patiënten. De groepen waren vergelijkbaar in BMI, cardiovasculaire risicofactoren, ASA-klasse (klinische conditie) en TASC-score (gradatie van de ziekte).

Operatietijd en aorta-klemtijd waren, zoals te verwachten, significant korter in de open groep. Bloedverlies was vergelijkbaar tussen beide groepen. Post-operatieve uitkomsten lieten een significant voordeel voor de robot geassisteerde groep zien: IC-verblijf was 1 dag (range 1 – 16) versus 2 dagen (range 1 – 6) ($p < 0.001$), herstarten van normaal dieet was op postoperatieve dag 2 (range 2 – 32) versus dag 5 (range 3 – 24) ($p < 0.001$), normale mobilisatie werd herstart op postoperatieve dag 3 (range 1 – 43) versus dag 4 (range 2 – 8) ($p < 0.001$) en het totale ziekenhuisverblijf was 6 dagen (range 3 – 57) versus 14.5 dagen (8 – 88).
Deze resultaten laten een belangrijke verbetering in de postoperatieve uitkomsten voor patiënten zien nadat robot geassisteerde aortachirurgie in ons ziekenhuis geïmplementeerd werd.

In **hoofdstuk zeven** is een systematische review beschreven, waarin een overzicht van de publicaties over laparoscopische vaatchirurgie wordt gegeven. De eerste publicaties komen uit 1993 en sindsdien zijn er slechts 30 originele patiëntenseries gepubliceerd.
In dit review worden series beschreven waarin zowel laparoscopie geassisteerde -, als handgeassisteerde laparoscopische -, als totaal laparoscopische -, als robot geassisteerde laparoscopische methodes worden toegepast voor zowel aneurysmatisch -, als occlusief aortoiliacaal vaatlijden. De series bestaan uit ten minste vijf patiënten.
De gepubliceerde series laten lange operatie – en aorta-klemtijden zien. Tevens bestaat er een aanzienlijke bias door patientenselectie, hetgeen het interpreteren van beschreven resultaten moeilijker maakt.
Een algemene conclusie in deze series was dat laparoscopische vaatchirurgie een tijdrovende en technisch zeer moeilijke procedure is. Het zou alléén moeten worden uitgevoerd in gespecialiseerde centra, door zeer specialistische en getrainde experts. Er werden slechts twee series beschreven waarin gebruik was gemaakt van robot geassisteerde laparoscopische chirurgie.

Tenslotte rapporteert **hoofdstuk acht** over een systematische review van robot geleide vaatchirurgie. Dit review was gedaan ten einde alle studies over dit onderwerp te beschrijven zonder enige exclusiecriteria. Totaal werden er vijf experimentele studies en vijf klinische studies beschreven, waarin gebruik werd gemaakt van óf het Zeus-Aesop –, óf het da Vinci robotsysteem.
De experimentele studies beschrijven robotchirurgie om een aorta-anastomose te maken. De resultaten laten géén significant verschil in uitkomst zien als het Zeus-Aesop systeem wordt vergeleken met conventionele laparoscopie, echter een meer accurate anastomose werd in minder tijd aangelegd als gebruik gemaakt werd van het da Vinci systeem.
Klinische studies beschrijven in totaal 70 patiënten, behandeld voor zowel aneurysmatisch -, als occlusief aortoiliacaal vaatlijden. De resultaten laten een operatietijd tussen 188 en 480 minuten zien, met een anastomosetijd van 27 tot 40.8 minuten. Het totale ziekenhuisverblijf varieerde van 4 tot 7.3 dagen en er werd in 10 % van de gevallen geconverteerd naar open chirurgie.
Dit laatste hoofdstuk laat zien dat er nog een gebrek aan bewijs is vóór robot geassisteerde aortachirurgie; er is weinig over gepubliceerd en de series zijn klein. Echter, de publicaties tonen wél de veiligheid en haalbaarheid van robot geassisteerde aortachirurgie aan.
Prospectief, gerandomiseerd onderzoek zal de rol van robotica in aortachirugie in de toekomst moeten vaststellen.

Conclusies

- Laparoscopische chirurgie heeft voordeel bij het gebruik van instrumenten met meer vrijheidsgraden. Dit fenomeen, wat duidelijk gedemonstreerd werd in verschillende basale oefeningen waarbij gebruik gemaakt werd van de minimal invasive manipulator, lijkt nog explicieter naar voren te komen tijdens het uitvoeren van gevorderde laparoscopische oefeningen.

- Robot geassisteerde vervaardiging van een aorta-anastomose is technisch veeleisend en het is vrijwel onmogelijk dit te volbrengen zonder de hechtdraad met het instrument vast te pakken. Voornamelijk gezien het ontbreken van gevoelsterugkoppeling in de huidige robotsystemen, is het essentieel het juiste hechtmateriaal te kiezen om zo een veilige en duurzame anastomose te kunnen garanderen.

- Robot geassisteerde laparoscopische chirurgie voor aortoiliacaal occlusief vaatlijden is een veilige en haalbare techniek, met acceptabele patiënten-uitkomsten. Desalniettemin zal er rekening gehouden moeten worden met lange operatie – en aorta-klemtijden als men voor het eerst deze techniek toepast.

- Assistentie van een robotsysteem in laparoscopische aortachirurgie zal een aanzienlijk kortere leercurve opleveren in vergelijking met conventionele laparoscopische aortachirurgie.

- Bij het laparoscopisch vrijprepareren van de aorta zijn er verschillende technieken bekend. De veiligste en meest stabiele techniek is een transabdominale benadering met toepassing van extreme patiëntrotatie (85 - 90°).

- Vergeleken met open chirurgie, laat robot geassisteerde laparoscopische chirurgie langere operatietijden zien, maar zijn de postoperatieve uitkomsten significant beter.

- Het gebrek aan publicaties over laparoscopische aortachirurgie is een indicatie van de technische moeilijkheid van deze techniek en zijn lange leercurve.

- Robot geleide vaatchirurgie is een veelbelovend nieuw, minimaal invasief, alternatief voor open – en endovasculaire chirurgie. Hoewel de haalbaarheid en veiligheid ervan zijn gedemonstreerd, zijn er weinig systematische studies in de literatuur te vinden en – om een definitieve rol te kunnen vervullen binnen de aortachirurgie – zal er meer onderzoek naar dit onderwerp gedaan moeten worden.

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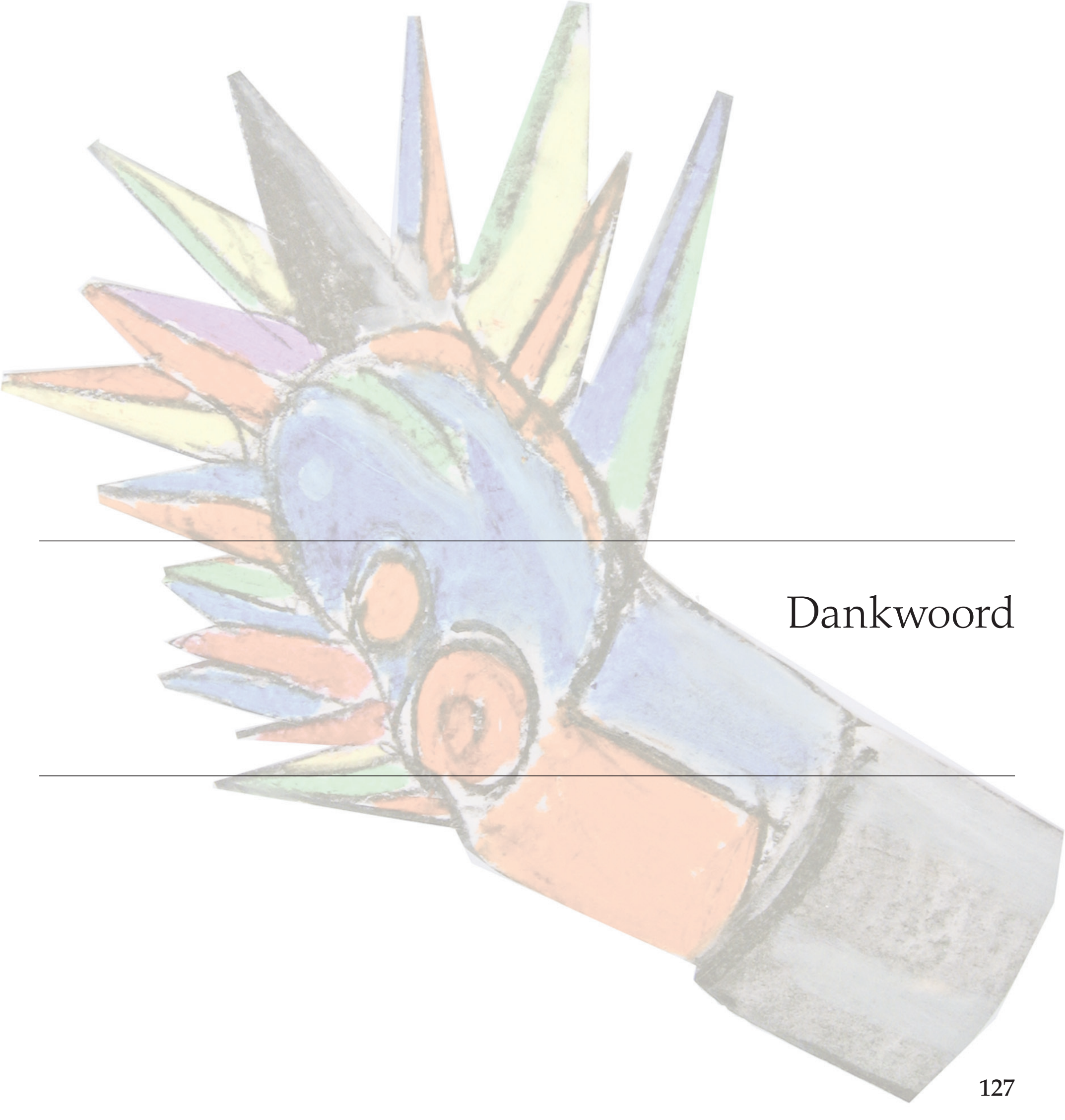

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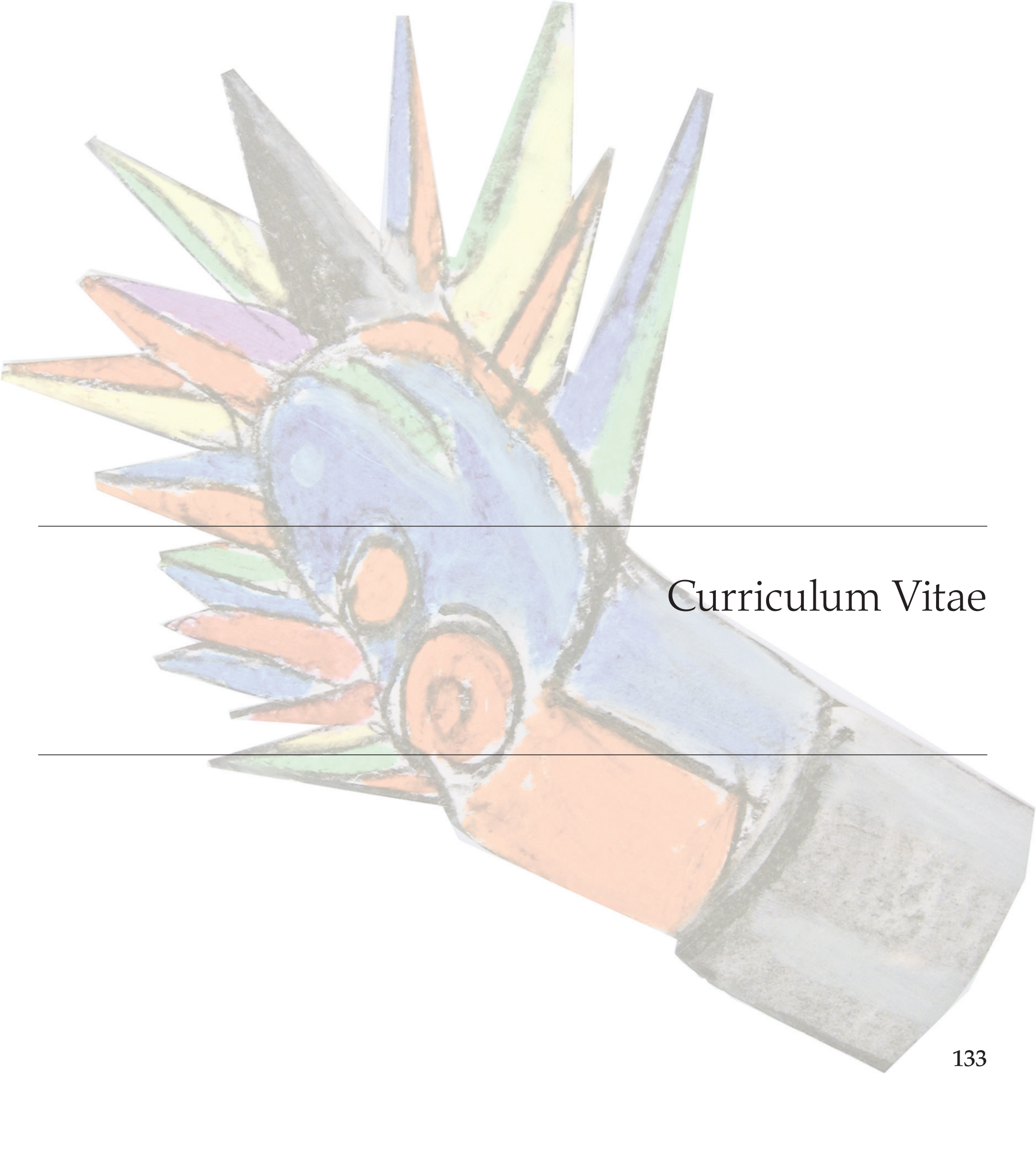

Curriculum Vitae

Jeroen Diks was born on May 21st 1977 at the Sint Andreas ziekenhuis in **Amsterdam**. He grew up in a little village, **Nes aan de Amstel**, where he went to primary school at the Sint Jozefschool.

In **Amsterdam**, he attended secondary school at the Montessori Lyceum Amsterdam, from 1989 until his graduation in 1995. After secondary school he went to **Bilbao, Spain** where he went to the Escuela official de Idiomas until spring of 1997.

At the Vrije Universiteit in **Amsterdam**, he attended his study Medicine and passed his doctoral exam in 2002. In 2003 he went to **Madrid** for half a year to do his surgical internships at the Hospital General Universitario Gregorio Marañon, after which he interrupted his internships to set up his research. He resumed his internships in 2005 and obtained his medical degree in October 2006. After a brief period (3 months) of residency at the Vrije Universiteit, he started as a resident in **Hoofddorp** at the Spaarne ziekenhuis. In December 2007 he switched to the Academisch Medisch Centrum in **Amsterdam**. Here he got admitted to the surgical training program in April 2008.

He started his training at the Albert Schweitzer Ziekenhuis in **Dordrecht** on July 1st 2008 and moved to **Rotterdam** in September 2008.